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ENGINEERING DEPARTMENT

TECHNICAL NOTE

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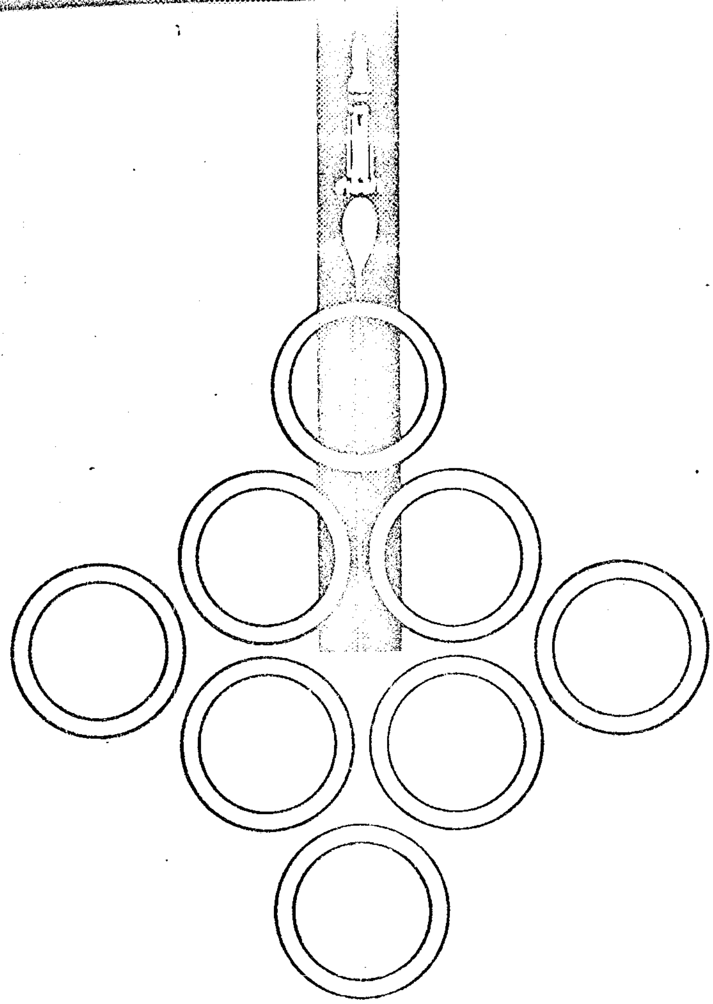

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SATURN IB/CENTAUR PROPULSION SYSTEMS COMPATIBILITY STUDY

SPACE DIVISION CHRYSLER CORPORATION

TECHNICAL NOTE

TN-AE-65-106

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August 6, 1965

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SECTION I – INTRODUCTION

This study was conducted as part of an overall Chrysler Corporation Space Division in-house effort covering the essentials of part I of a definition phase on the Saturn IB/Centaur integration task. As such, investigations of the propulsion systems of the three-stage Saturn IB/Centaur launch vehicle, figure I-1, were undertaken for the following purposes:

1. Identify Centaur vehicle and GSE equipment.
2. Evaluate compatibility with existing Saturn IB systems.
3. Determine qualification for service of on-board equipment and GSE equipment for each stage.
4. Define modifications required to achieve service status.

The data contained herein represents an extension of the information presented in the report "Saturn IB Centaur Integration", Engineering Department Technical Report TR-AE-65-5, Chrysler Corporation Space Division, June, 1965.

References used as data sources on this document are shown in appendix B.

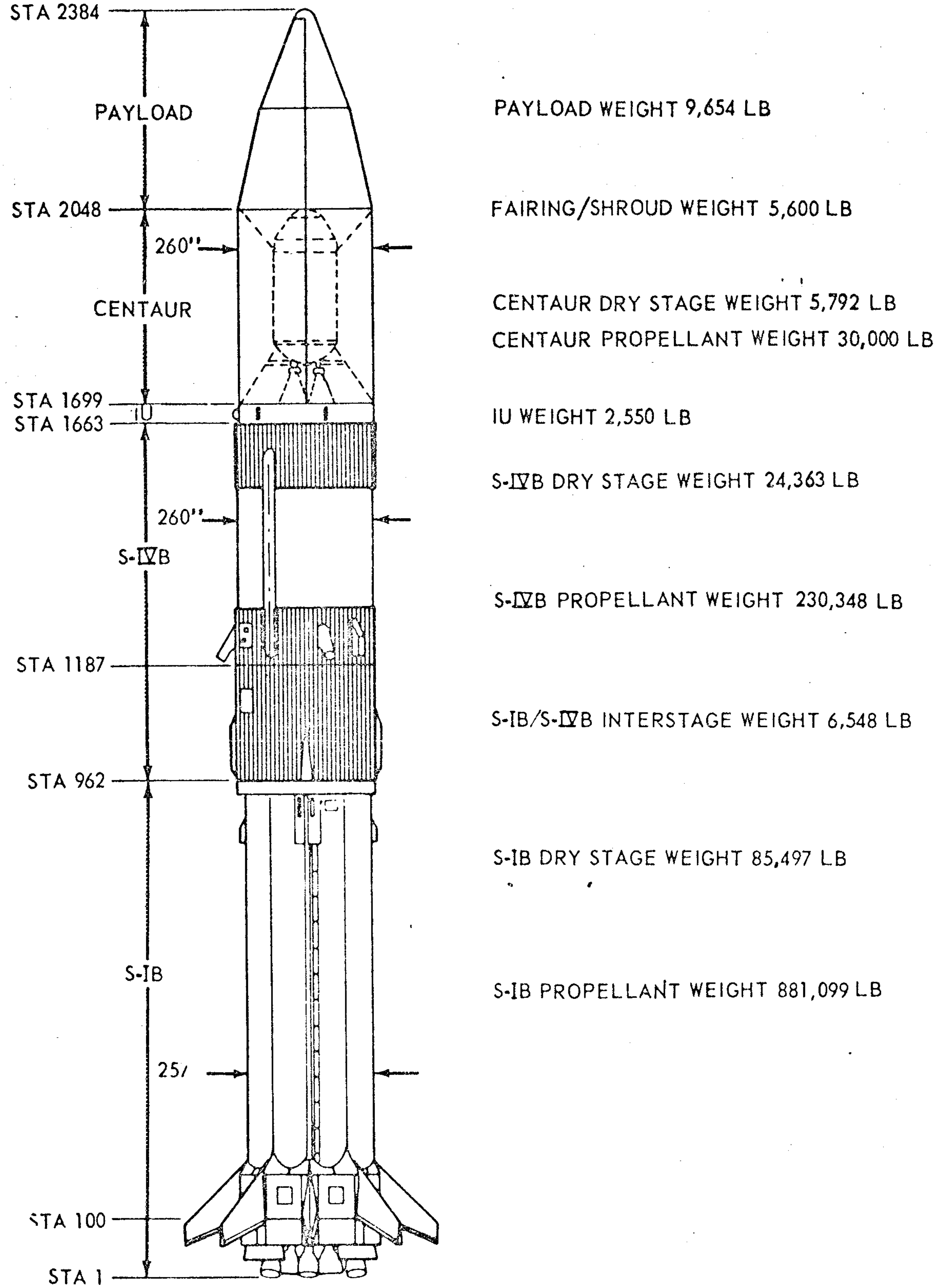

Figure I-1. Saturn IB/Centaur Launch Vehicle

SECTION II – SUMMARY

Centaur stage propulsion and GSE equipment have been identified and evaluated for compatibility with existing Saturn IB systems. Changes required in the propulsion systems of the S-IB, S-IVB, and Centaur stages that make up the Saturn IB/Centaur basic launch vehicle are minimal. Areas of recommended new or modified design are identified in table II-1. The majority of the required changes are in the Centaur stage and are due, primarily, to the shrouded Centaur configuration and, secondarily, to auxiliary propulsion requirements.

Table II-1. Baseline Saturn IB/Centaur Launch Vehicle Recommended Propulsion Systems Changes

Ref: SA-208 for S-IB, S-IVB
AC-12 for Centaur

Stage	Subsystem	Design Change		Requirements
		Type	Description	
S-IB		No Modification required		
S-IVB	Aux. Propulsion	Add	4 5500-lb retro rockets	S-IVB/Centaur separation
Centaur	Engine Childown	Modify	Relocate ducting, collector manifold, and vent	Ground and flight childown
	Umbilicals (All Fluids Systems)	Add	Lines, conduit, supports, disconnects, disconnect panels, lanyards	Shroud-to-Centaur continuity for servicing, checkout, liftoff and in-flight separation (as required)
	Pneumatic Control	Add	Vehicle-borne pneumatic latching mechanisms	In-flight umbilical disconnect, if dual disconnect scheme used
	Helium Storage	Modify	Increase capacity	Propellant tank and H_2O_2 storage tank pressurization and pneumatic control
	Vacuum	Modify	Delete intermediate bulkhead evacuation requirement	Intermediate bulkhead thermal barrier
	Propellant Tank Vents	Modify	Relocate to dump overboard	Ground and boost flight venting
	H_2O_2 Storage	Modify	Double present capacity	Boost Pump and Aux. Propulsion

Table II-1. Baseline Saturn IB/Centaur Launch Vehicle Recommended Propulsion Systems Changes (Continued)

Stage	Subsystem	Design Change		Requirements
		Type	Description	
Centaur (Cont'd)	Aux. Propulsion	Add (from AC-4)	4 50-lb H_2O_2 nozzles	Preignition propellant settling
		Modify (from AC-4)	2 2-lb to 2 3-lb nozzles	Continuous coast phase propellant settling
		Add	4 1200-lb thrust solid retro rockets	Centaur/Payload separation
		Add	2 cold-gas jets and storage spheres, or 16 200-lb thrust solid rockets	Shroud separation
	LH_2 Tank	Add	Anti-slosh baffle	Dampen propellant slosh

SECTION III – S-IB STAGE PROPULSION SYSTEMS

Addition of the Centaur stage to the basic Saturn IB launch vehicle will require no changes to the S-IB stage propulsion system. Vehicle acceleration profiles shown in table A-2 were used as the comparison criterion for the S-IB study. Since the accelerations are essentially unchanged from the current S-IB data projections, no changes are required to the rocket engines, LO_2 tank pressurization system, fuel (RP-1) tank pressurization system, propellant systems, or auxiliary pressurization or hydraulic systems.

Existing qualification requirements, reliability test requirements, and acceptance test requirements of propulsion components will not be affected.

A brief description of the major system elements is presented below.

A. H-1 ENGINE SYSTEM

The H-1 rocket engine system is a fixed thrust, bipropellant, single start system utilizing a hypergolic fluid for primary ignition of the propellants, liquid oxygen (LO_2), and RP-1 fuel. The engine system consists of the following major components: thrust chamber, gas generator assembly, turbopump, main LO_2 valve, main fuel valve, igniter fuel valve, conax valve, hypergol container, ignition monitor valve, pressurant heat exchanger, and fuel additive blender unit. Components of the gas generator include a solid propellant cartridge for turbine start power and a combustor assembly for liquid propellant boot-strap operation. An engine data summary is presented in table III-1.

B. S-IB PROPELLANT SYSTEM

1. Fuel System

The fuel system receives, stores, and transfers fuel to the engines. System elements include four tanks, various valves, ducts and control devices for filling, draining, and leveling of the fuel. Each tank supplies one inboard and one outboard engine. The four tanks are interconnected at the top and bottom by manifolds which maintain uniform fuel pressure and level at all times. Therefore, should an engine fail at any time, uniform fuel pressure and level would be maintained in all tanks, and the fuel intended for the engine that failed would be supplied to the remaining engines. No modifications are required in this system.

Table III-1. H-1 Engine Data Summary*

*Ref – Rocketdyne Div. NAA "Engine Data H-1 Rocket Engine", 18 June 1965, Rev. 12 April 1965.

Performance (At Standard Inlet Conditions)	Value
Thrust (S. L.)	200,000 ± 3% lb.
Specific Impulse, Nominal	260.5 sec
Specific Impulse, Minimum	258.0 sec
Mixture Ratio, Nominal	2.23 ± 2%
Chamber Pressure (Nozzle Stagnation), Nominal	633 psia
Run Duration, Minimum	155 sec
Thrust Coefficient (Nozzle Conditions)	1.527
Propellant Inlet Conditions	
Fuel Pressure, Start	57 psia
Fuel Pressure, Run	57 psia
Fuel NPSH, Min.	35 ft
Fuel Temperature, Start	0 to 110°F
Fuel Temperature, Run	35 to 96°F
Fuel Density, Midpoint	50.45 lb/ft^3
Oxidizer Pressure, Start	80 psia
Oxidizer Pressure, Run	65 psia
Oxidizer NPSH, Min.	35 ft
Oxidizer Temperature, Start	-300 to -275°F
Oxidizer Temperature, Run	-300 to -280°F
Oxidizer Density, Midpoint	70.79 lb/ft^3
Dimensions and Description	
Type – Regeneratively Cooled, Turbopump Fed, Liquid Oxygen, RP-1, Rocket Engine	
Gimbal Angle	± 10° (Square Pattern)
Engine Diameter (Chamber)	49.6 in
Engine Length (Overall)	104.2 in
Nozzle Area Ratio	8:1
Weight	
Dry, Including Accessories – Inboard	1713 lb
– Outboard	1951 lb
Engine Fluids at Burnout	165 lb

2. LO_2 System

Storage and supply of LO_2 to the engines is the function of the LO_2 system. The LO_2 system consists of one central tank and four outer tanks, various valves, ducts, and control devices for filling, draining, venting and replenishing of the tanks, and for supplying LO_2 to the engines. Each outer LO_2 tank supplies one inboard and one outboard engine. All five tanks are connected at the top and the bottom in the same manner as the fuel tanks. Therefore, should an engine fail at any time, uniform LO_2 level and pressure would be maintained in all tanks and all LO_2 would be supplied to the remaining engines. No modifications are required.

C. S-IB PRESSURIZATION SYSTEM

1. Control Pressure System

Pressurized nitrogen gas (GN_2) is stored by the control pressure system for use on demand by several electro-pneumatic control valves. These valves, upon receipt of a command signal, open or close to permit control pressure to actuate various pneumatic-mechanical valves in the fuel and LO_2 systems. The system also supplies GN_2 for calorimeter purging, and to the engine turbopumps for gearbox pressurization and LO_2 seal purging. The major components of this system are: a high pressure sphere, a high pressure switch, a regulator, a 750 psi switch, and related couplings and valves. No system changes are required.

2. Radiation Calorimeter Purge System

The radiation calorimeter purge system helps to assure proper operation of the calorimeter by preventing deposit of combustion products or other foreign material on the sapphire window by purging with GN_2. These are two calorimeters currently used in the system. No modifications are required.

3. LO_2 Pump Seal and Gear Box Pressurization System

The LO_2 pump seal purge reduces the explosive hazard from LO_2 and lubricant leakage. Gearbox pressurization improves the quality of the lubricant by reduction of foaming at high altitudes. The purge/pressurant gas is nitrogen. No changes are required.

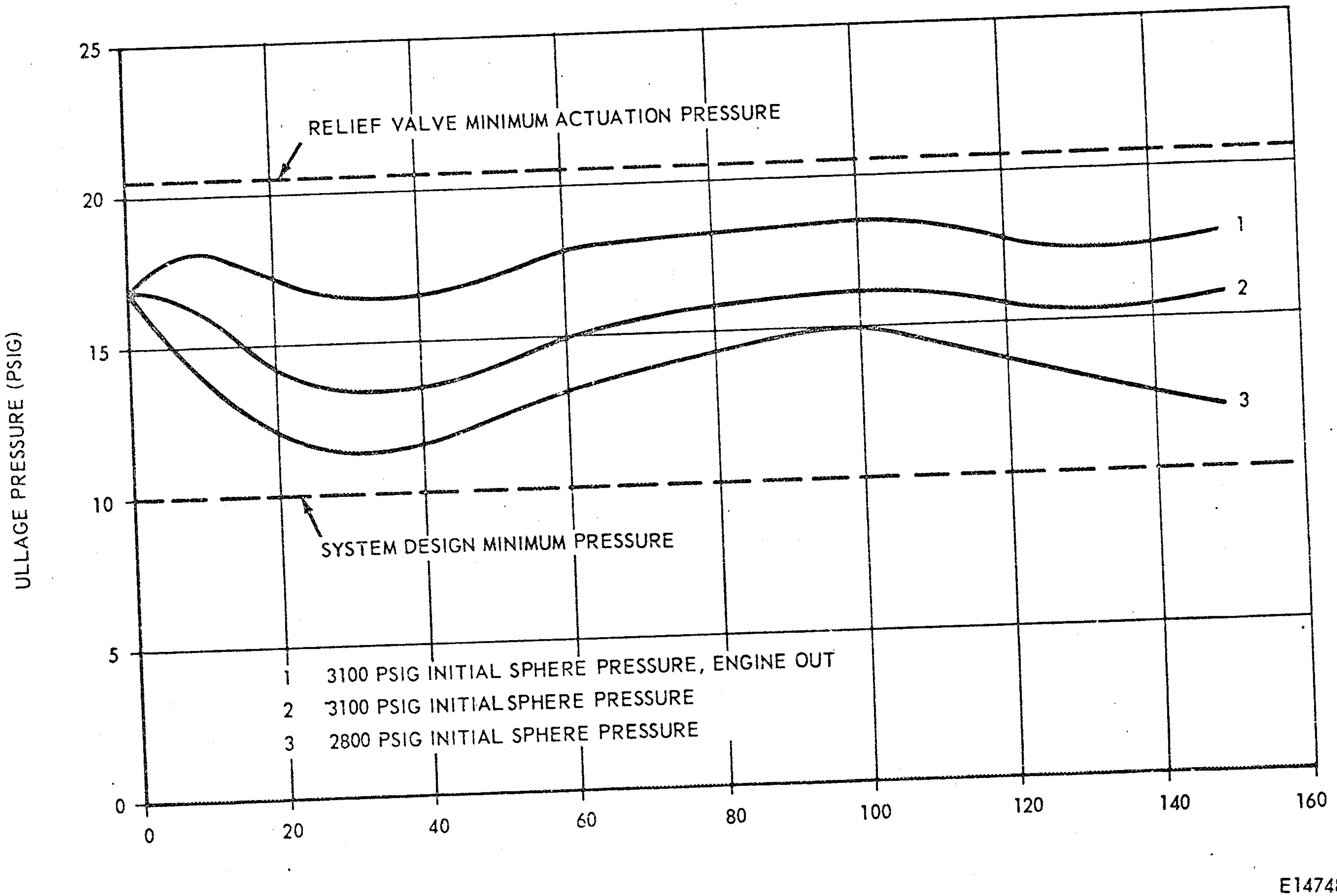

Figure III-1. S-IB RP-1 Tank Pressures (Typical)

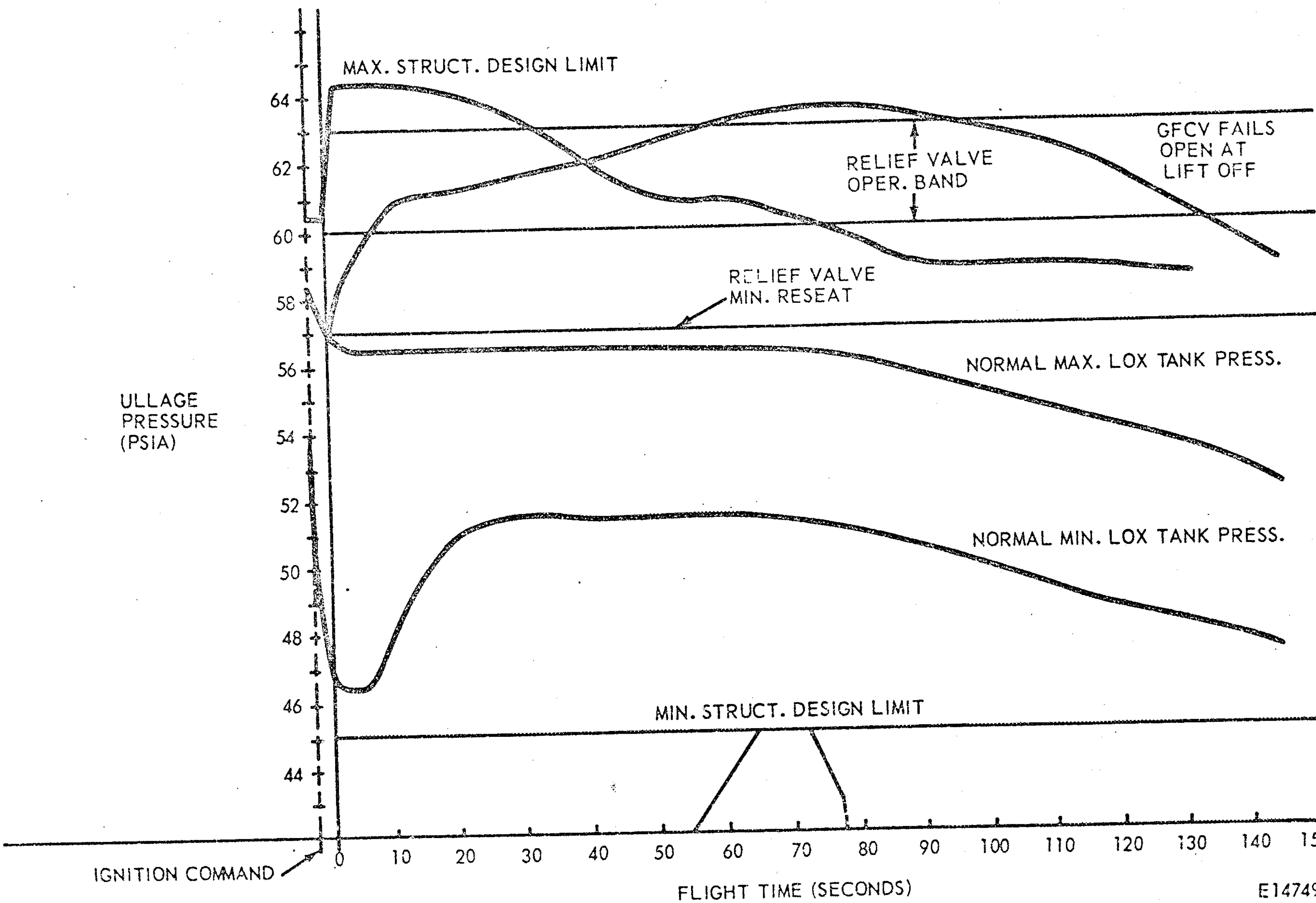

Figure III-2. S-IB LO_2 Tank Pressures (Typical)

4. Fuel Tank Pressurization System

A fuel tank pressurization system maintains required net positive suction head (NPSH) to the engine turbopumps and provides pneumatic support to the fuel tank structures. Typical supplied pressure profiles are shown in figure III-1. The major components of the system are two pressurant storage spheres, pressurization valves, a pressure switch, associated valves, a filter, sonic nozzle, and tubing. Vent valves are provided for over-pressure relief during prelaunch operations. The pressurant gas is helium. No changes are required since vehicle acceleration profiles are unchanged.

5. LO_2 Tank Pressurization System

The LO_2 tank pressurization requirements are satisfied by a prelaunch charge of helium gas and by inflight pressurization by hot GO_2 vapors generated from LO_2 in a heat exchanger located in each turbine exhaust. Typical tank pressure profiles are shown in figure III-2. The major components are orifices, heat exchangers, a collector manifold, a GO_2 flow control valve, and distribution manifold. Vent valves are provided for overpressure relief. No modifications are required since vehicle acceleration profiles are unchanged.

D. S-IB HYDRAULIC SYSTEM

Each outboard engine is equipped with a hydraulic system to provide power for vehicle flight control through engine gimbaling. Each hydraulic system is an independent closed loop system designed to eliminate the need for an external hydraulic pressurizing source. Major components of each system are two hydraulic actuators, a main pump, an auxiliary pump and motor, and an accumulator-reservoir manifold assembly. No system changes are required.

E. S-IB GSE MECHANICAL SYSTEM

The following vehicle connections are required for servicing and are separated from ground connections at liftoff:

1. Umbilical Swing Arm (Sta. 920)

   a. Fill Line Coupling (Fuel Pressurization), GHe

   b. Fuel Density Computer and Fuel Tanking Computer Coupling

   c. Fuel Tanking Computer Coupling

d. Fuel Density Computer Coupling

e. LO_2 Vent Valves 1 and 3 Control Line

2. Umbilical Fin II (Sta. 145.375)

   a. Fuel Fill and Drain Control Coupling

   b. Prevalve Closing Control Coupling

   c. Fuel Injector Purge Coupling, GN_2

   d. LO_2 Dome Purge (Inboard and Outboard) Coupling, GN_2

   e. Fuel Bubbling Coupling, GN_2

   f. LO_2 Pressurization Coupling (Ground), GHe

   g. Opening Control LO_2 Tank Vents 2 and 4, Fuel Tank Vents Coupling

3. Umbilical Fin IV (Sta. 145.375)

   a. LO_2 Fill and Drain Control Coupling

   b. LO_2 Replenishing Opening Control Coupling

   c. Control Sphere Fill Coupling, GN_2

   d. GG LOX Injector Purge Coupling, GN_2

   e. LO_2 Bubbling Coupling, GHe

   f. LO_2 Sensing, Bottom, Coupling

   g. LO_2 Sensing, Top, Coupling

   h. Water Quench Control Line

4. Tail Connections

   a. Fuel Fill and Drain Coupling

   b. LOX Replenishing Coupling

   c. LOX Fill and Drain Coupling

   d. Boattail Conditioning and Water Quence Valve

No changes are required in the existing S-IB Stage GSE.

F. S-IB PROPULSION COMPONENT QUALIFICATION

Preliminary evaluation has shown that the environmental levels experienced on the S-IB stage of the Saturn IB/Centaur launch vehicle will not exceed the environmental specification levels of the basic Saturn IB vehicle. Therefore, no component requalification is required.

SECTION IV. S-IVB STAGE PROPULSION SYSTEMS

The S-IVB stage of the Saturn IB vehicle will be used in the Saturn IB/Centaur configuration without major modification; however, an additional system to provide for S-IVB/Centaur separation will be added.

A brief functional description of the major S-IVB subsystems is provided in the following paragraphs.

A. J-2 ENGINE SYSTEM

The S-IVB is powered by a single Rocketdyne J-2 engine that uses LO_2 and LH_2 propellant at a nominal mixture ratio of 5 to 1. The J-2 is a high-energy engine delivering a nomi al 200,000 pounds of thrust in vacuum. The engine has a tubular wall, bell-shaped, regeneratively cooled thrust chamber with an expansion ratio of 27.5 to 1. Independently driven, direct-drive turbopumps increase LO_2 pressure to chamber ducting. A single gas generator provides LO_2/LH_2 combustion gases to sustain the LO_2 centrifugal and LH_2 axial turbopumps. A servo-motor driven propellant utilization valve mounted on the LO_2 turbopump controls engine LO_2 consumption, controlling engine burned mixture ratio.

Gimbal mounting permits the engine to be swiveled seven degrees from the null position in a square pattern for both vehicle steering and attitude control. Power for gimballing is supplied by a hydraulic control system mounted on the engine.

An engine mounted heat exchanger heats cryogenic helium expanded from storage spheres located in the LH_2 tank for pressurization of the LO_2 tank. The heat exchanger utilizes heat from the turbine exhaust. The GH_2 bleed from the engine satisfies LH_2 tank pressurization.

Electrical signals control the flow of GHe from an engine-mounted sphere which actuates valves for starting and stopping the engine. Engine ignition is accomplished by an electrical spark plug ignition system. An engine mounted GH_2 "blow-down" start tank provides the initial drive for the turbopump turbines prior to gas generator ignition.

An engine data summary is presented in table IV-1. The engine can be used in Saturn IB/Centaur as presently designed for SA-204 and subsequent vehicles.

Table IV-1. J-2 Engine Data Summary*

*Ref – Rocketdyne Div. NAA "Engine Data J-2 Rocket Engine", 18 June 1964, Rev. 13 May 1965.

	Value
Performance (At Standard Inlet Conditions)	
Thrust (Vac.)	200,000 ± 3% lb
Specific Impulse, Nominal	--
Mixture Ratio, Nominal	5:1
Chamber Pressure (Nozzle Stagnation), Nominal	630.7 psia
Thrust Coefficient (Nozzle Conditions)	--
Run Duration	500 sec
Propellant Inlet Conditions	
Fuel Pressure, Run	30 psia
Fuel NPSH, Min	120 ft
Fuel Temperature, Mean	37.156°R
Fuel Density, Mean	4.40 lb/ft^3
Oxidizer Pressure, Run	39 psia
Oxidizer NPSH, Min	21.7 ft
Oxidizer Temperature, Mean	164.476°R
Oxidizer Density, Mean	70.79 lb/ft^3
Dimensions and Description	
Type – Regeneratively Cooled, Turbopump Fed, Liquid Oxygen, Liquid Hydrogen, Rocket Engine	
Gimbal Angle	± 7° (Square Pattern)
Engine Diameter (Chamber)	80.75 in
Engine Length (Overall)	133 in
Nozzle Area Ratio	27.5:1
Weight	
Dry, Including Accessories	3,480 lb
Burnout	3,609 lb

SECTION IV. S-IVB STAGE PROPULSION SYSTEMS

The S-IVB stage of the Saturn IB vehicle will be used in the Saturn IB/Centaur configuration without major modification; however, an additional system to provide for S-IVB/Centaur separation will be added.

A brief functional description of the major S-IVB subsystems is provided in the following paragraphs.

A. J-2 ENGINE SYSTEM

The S-IVB is powered by a single Rocketdyne J-2 engine that uses LO_2 and LH_2 propellant at a nominal mixture ratio of 5 to 1. The J-2 is a high-energy engine delivering a nominal 200,000 pounds of thrust in vacuum. The engine has a tubular wall, bell-shaped, regeneratively cooled thrust chamber with an expansion ratio of 27.5 to 1. Independently driven, direct-drive turbopumps increase LO_2 pressure to chamber ducting. A single gas generator provides LO_2/LH_2 combustion gases to sustain the LO_2 centrifugal and LH_2 axial turbopumps. A servo-motor driven propellant utilization valve mounted on the LO_2 turbopump controls engine LO_2 consumption, controlling engine burned mixture ratio.

Gimbal mounting permits the engine to be swiveled seven degrees from the null position in a square pattern for both vehicle steering and attitude control. Power for gimballing is supplied by a hydraulic control system mounted on the engine.

An engine mounted heat exchanger heats cryogenic helium expanded from storage spheres located in the LH_2 tank for pressurization of the LO_2 tank. The heat exchanger utilizes heat from the turbine exhaust. The GH_2 bleed from the engine satisfies LH_2 tank pressurization.

Electrical signals control the flow of GHe from an engine-mounted sphere which actuates valves for starting and stopping the engine. Engine ignition is accomplished by an electrical spark plug ignition system. An engine mounted GH_2 "blow-down" start tank provides the initial drive for the turbopump turbines prior to gas generator ignition.

An engine data summary is presented in table IV-1. The engine can be used in Saturn IB/Centaur as presently designed for SA-204 and subsequent vehicles.

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Thrust (Vac.)	200,000 ± 3% lb
Specific Impulse, Nominal	--
Mixture Ratio, Nominal	5:1
Chamber Pressure (Nozzle Stagnation), Nominal	630.7 psia
Thrust Coefficient (Nozzle Conditions)	--
Run Duration	500 sec
Propellant Inlet Conditions	
Fuel Pressure, Run	30 psia
Fuel NPSH, Min	120 ft
Fuel Temperature, Mean	37.156°R
Fuel Density, Mean	4.40 lb/ft^3
Oxidizer Pressure, Run	39 psia
Oxidizer NPSH, Min	21.7 ft
Oxidizer Temperature, Mean	164.476°R
Oxidizer Density, Mean	70.79 lb/ft^3
Dimensions and Description	
Type – Regeneratively Cooled, Turbopump Fed, Liquid Oxygen, Liquid Hydrogen, Rocket Engine	
Gimbal Angle	± 7° (Square Pattern)
Engine Diameter (Chamber)	80.75 in
Engine Length (Overall)	133 in
Nozzle Area Ratio	27.5:1
Weight	
Dry, Including Accessories	3,480 lb
Burnout	3,609 lb

B. S-IVB PRESSURIZATION SYSTEM

The pressurization system provides the necessary propellant tank ullage pressure to satisfy the NPSH requirements of the J-2 engine turbopumps, and maintains the structural integrity of the fuel tank under axial acceleration loads and aerodynamically induced bending moments during boost and powered flight. Typical tank pressure profiles are shown in figure IV-1 and IV-2.

No modifications to the basic S-IVB pressurization system are anticipated for use in the Saturn IB/Centaur configuration, based on presently available information. Performance evaluations have shown that the longitudinal acceleration experienced by the Saturn IB/Centaur is approximately the same as that experienced by Saturn IB and should not necessitate modification of either tank wall gages or pressure levels.

1. Oxidizer Tank Pressurization

Helium is used to pressurize the LO_2 tank during launch standby, S-IB boost, and S-IVB powered flight. The LO_2 tank is prepressurized by a ground supply of cold helium to 39.5 psia. Inflight pressurization is provided by helium from eight storage spheres. pressurized initially to 3100 psi, located in the fuel tank.

When J-2 engine ignition is detected, a control signal will allow helium to flow from the cold helium supply through a regulator, reducing pressure to 400 psia, through a shutoff valve, past a plenum chamber and into a manifold. A portion of the cold helium flows from the manifold through an orifice to the J-2 engine heat exchanger where it is heated and expanded. Another portion bypasses the heat exchanger and is mixed with the outflow from the heat exchanger. The combined flow is directed into the LO_2 tank. An additional parallel branch high capacity helium supply line is provided to augment tank pressure during engine firing. When LO_2 tank pressure decays to 38 PSIA, a pressure switch signals the augmentation solenoid valve to open permitting additional flow of helium from the manifold through the heat exchanger, to raise LO_2 tank pressure. When pressure reaches 41 PSIA, the pressure switch closes the augmentation valve. The LO_2 pressure thus cycles between approximately 38 and 41 psia.

A LO_2 tank vent-relief system is provided to automatically relieve pressure in excess of 44 PSIA and to reseat at 41 PSIA.

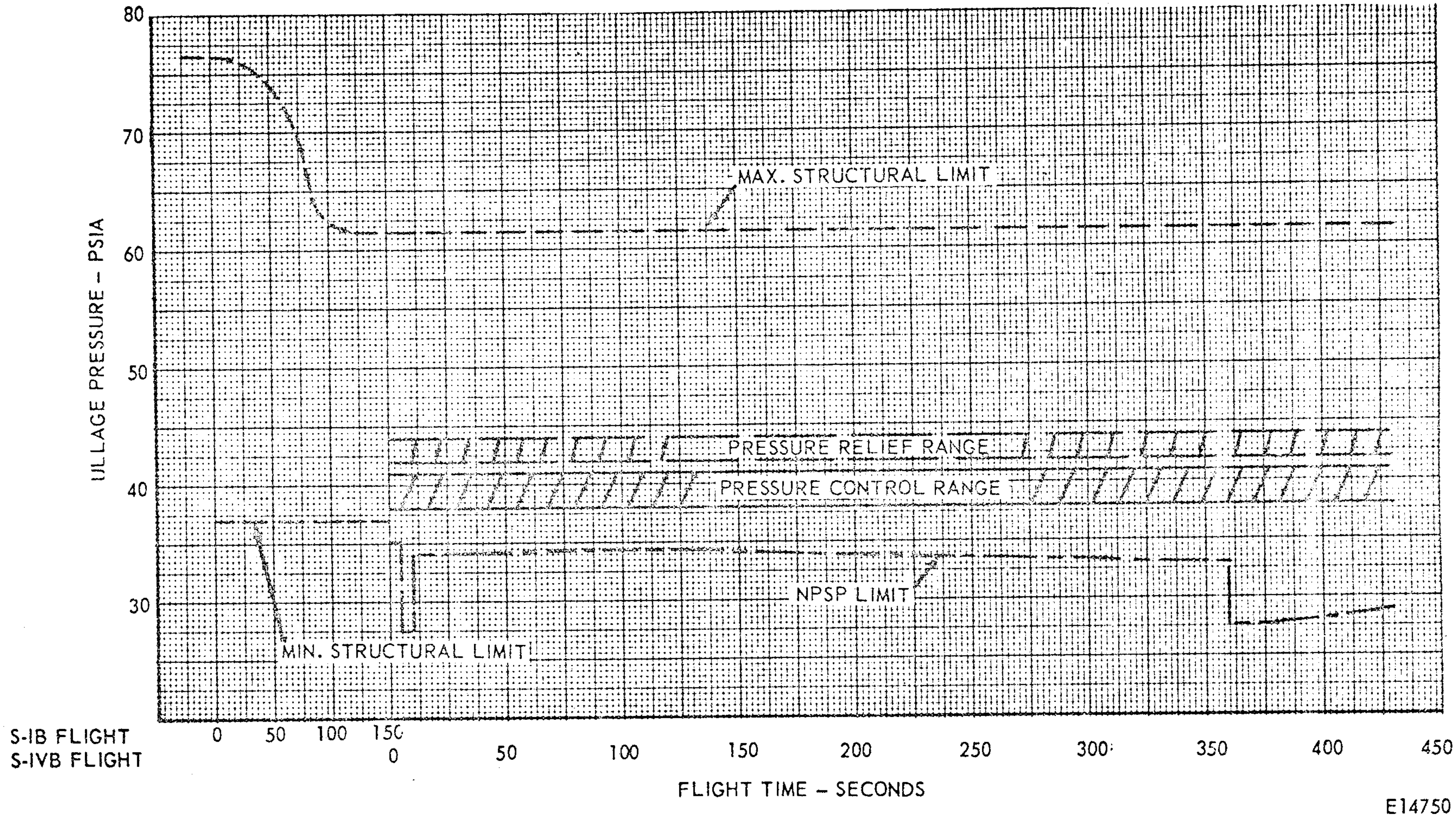


Figure IV-1. S-IVB LO_2 Tank Pressure (Ref: SA-204)

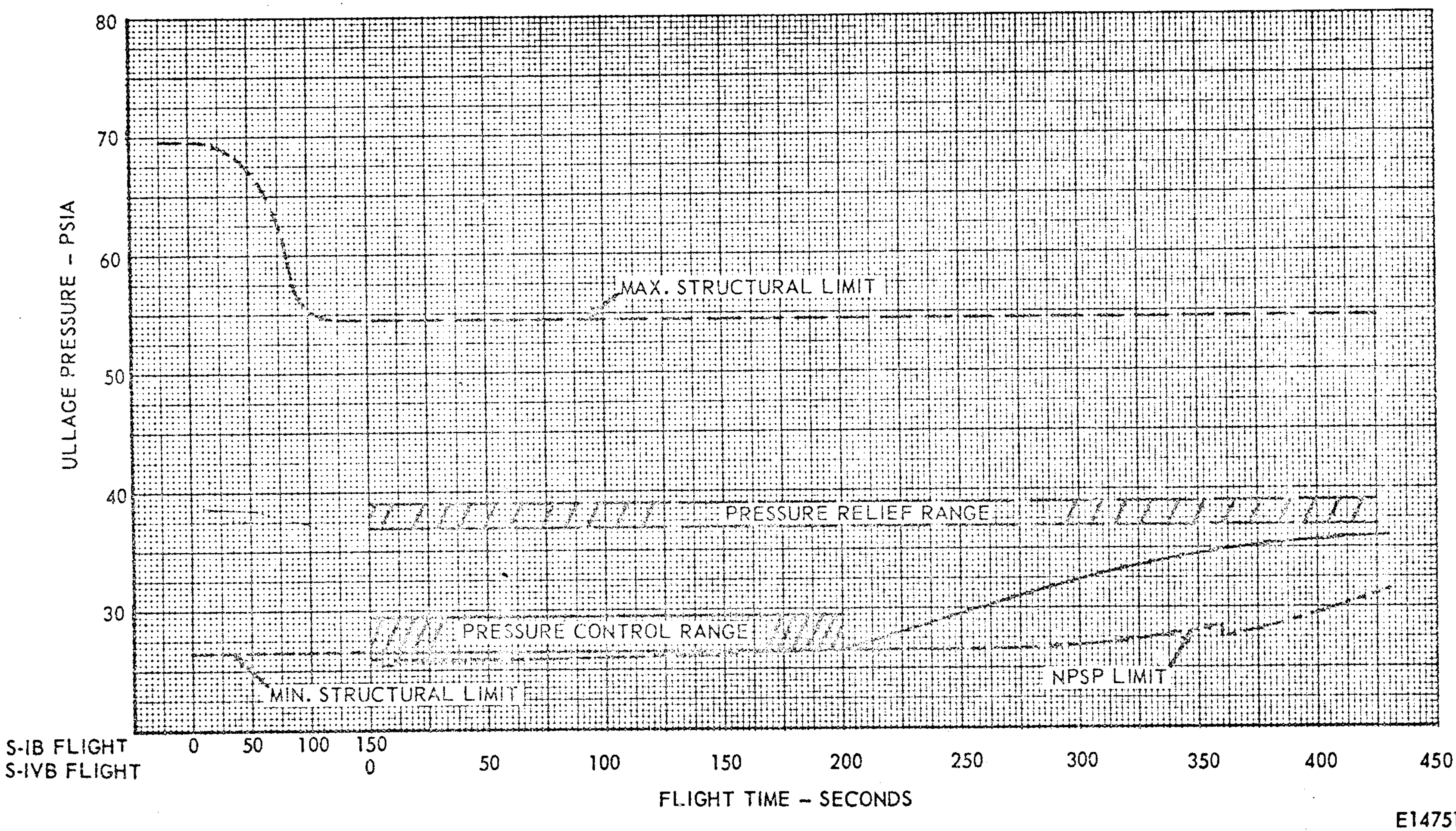


Figure IV-2. S-IVB LH_2 Tank Pressure (Ref: SA-204)

2. Fuel Tank Pressurization

The fuel tank ullage pressure is maintained at the proper operating level by helium prior to J-2 engine ignition and by GH_2, bled from the J-2 engine, during S-IVB powered flight.

The fuel tank is prepressurized to 29.5 psia from cold (-360°F) ground helium supply. During boost flight, tank pressure will remain approximately at liftoff value, ensuring sufficient pressure for engine start. During engine firing, GH_2 is bled from the J-2 engine at 750 psia and -260°F to maintain tank pressure. Engine bleed flow is routed to the LH_2 tank ullage supply line through three parallel branches. Each branch contains an orifice; one branch contains a control valve, a second branch contains a step valve, and a third branch provides continuous pressurant flow while the J-2 engine is firing. Initially, the control valve and step valve are held closed. As fuel is being pumped from the tank, pressure decays to 26.5 psia and the control valve opens to admit flow through the control branch. When pressure builds to 29 psia the control valve closes. The step pressure valve is held closed for the first 200 seconds of engine burn, then opens to allow pressure to build up to vent pressure at 39 psia, venting overboard through the relief valve. The vent-relief is controlled to open at 39 psia and close at 37 psia.

C. S-IVB PNEUMATIC CONTROL SYSTEM

A Pneumatic Control System provides GHe to operate all S-IVB stage pneumatically-operated valves except the engine valves. The GHe is supplied from a sphere which is precharged to 3100 psia at 70°F from ground facilities. This sphere, located on the forward side of the thrust structure, is conditioned to above 70°F by the Environmental Control System during ground operations. A pneumatic control module filters and regulates helium pressure to 475 psia before routing to other control modules.

In addition to operating valves, the GHe system also provides He for purging the LH_2 and LO_2 turbopump seal cavities and gas generator fuel manifold. Purging starts ten minutes before admitting propellants to the engine.

The Pneumatic Control System will not require modification for Saturn IB/Centaur application.

D. S-IVB PROPELLANT SYSTEM

The S-IVB stage contains a single propellant tank assembly that is composed of a fuel tank and an oxidizer tank. The 2828 cubic foot LO_2 tank is mounted below and is separated from the fuel tank by an evacuated, dual hemispherical bulkhead annulus. The LO_2 is supplied to the J-2 engine through a thermally insulated suction line that extends from the bottom of the tank to the J-2 engine oxidizer turbopump. A normally open pneumatically-operated prevalve in the LO_2 suction line controls LO_2 flow to the engine. The valve is closed to terminate LO_2 flow to the engine at J-2 engine cutoff.

A LO_2 circulation pump, mounted within the S-IVB stage LO_2 tank, circulates LO_2 through the suction line and the J-2 engine oxidizer turbopump prior to J-2 engine ignition to prevent temperature stratification in the suction line. The LO_2 circulate pump is in operation for approximately 15 minutes before vehicle liftoff and throughout the S-IB stage boost phase of vehicle flight.

The LH_2 is stored in a 10,426 cubic foot volume fuel tank portion of the propellant tank assembly. the LH_2 feed system is similar to the LO_2 feed system in that it includes a prevalve and circulation pump.

No system modifications are required.

E. S-IVB PROPELLANT UTILIZATION SYSTEM

A Propellant Utilization System (P.U.) is provided to minimize propellant residuals at stage burnout. The system controls mixture ratio (on a programmed basis or as a function of the mass ratio of the propellants in the tanks) as the tanks are being depleted. Capacitive type metering probes located in the oxidizer and fuel tanks provide capacitance output directly proportional to tank propellant mass. A propellant utilization system electronics assembly provides signals to a position servo motor which controls the LO_2 bypass valve on the J-2 engine. This valve diverts a portion of the flow from the discharge side of the oxidizer turbopump to the inlet side in proportion to the signal received from the P.U. system electronics assembly. The P.U. system may be activated at approximately separation plus 7.1 seconds.

The LO_2 bypass valve is also used to effect the programmed thrust level step of the J-2 engine during S-IVB powered flight. During the early portion of the J-2 operation the mixture ratio is held at 5.5:1 and the thrust at 230,000 lbs. After approximately 70 per cent of burn time, the LO_2 bypass valve reduces the mixture ratio to 4.7 : 1 and the thrust to 190,000 lbs.

No changes are required to this system.

F. S-IVB AUXILIARY PROPULSION SYSTEMS

The S-IVB auxiliary propulsion systems consist of the following:

1. Reaction control system
2. S-IB/S-IVB staging system
3. S-IVB/Centaur staging system

1. Reaction Control System

The Reaction Control System consists of two self-contained attitute control modules, mounted 180-degrees apart on the aft skirt. Each module contains three liquid bipropellant thrust motors and a propellant control system.

The thrust motors are pulse fired (30 ms minimum duration), and deliver 150 pounds of thrust at a chamber pressure of 100 psia and chamber temperature of approximately 5500°F.

The Propellant Control System includes an integral bellows-type propellant tank, a helium sphere, control valves, and plumbing. Helium from the storage sphere flows through a pressure regulator to provide positive expulsion pressure on collapsible metal bellows in the fuel and oxidizer tanks thereby expelling propellants from the tanks. The propellants are hypergolic and each module stores 25 pounds of Aerozine-50 and 40 pounds of nitrogen tetroxide. All control signals are supplied directly from the Instrument Unit to solenoid valves in the fuel and oxidizer lines.

The reaction control system provides pitch, yaw, and roll control during the S-IVB coast mode of operation and roll control during powered flight. Pitch and yaw control during powered flight is provided by the J-2 engine hydraulic system. In the Saturn IB/Centaur configuration only the roll control capability of the reaction control system is utilized as an S-IVB coast mode of operation is not required.

Modification to the reaction control system is not required for Saturn IB/Centaur use, although an existing pitch/yaw attitude control capability will not be used.

2. S-IB/S-IVB Staging System

In-flight separation of the S-IVB stage from the S-IB stage is programmed to occur after completion of the S-IB stage boost operation. The programmed time of separation is approximately 145.1 seconds after liftoff; however, the precise time of separation is dependent on S-IB stage propellant depletion and shutdown.

Three solid propellant ullage rockets (table IV-2) are mounted at 120-degree intervals on the aft skirt of the S-IVB stage and are canted outward at a 35-degree angle from the vehicle center line. Thrust from the ullage rockets imparts a forward acceleration to the S-IVB stage which forces the propellants to the J-2 engine pump inlet and also aids stage separation. The ullage rockets are ignited approximately 0.1 seconds before separation command, continue to burn for about 4 seconds, and are jettisoned about 10 seconds after burnout by firing 6 frangible nuts that attach the ullage rockets to the S-IVB stage.

Four solid propellant retrorockets (table IV-2) are mounted at 90-degree intervals around the S-IB/S-IVB interstage on an outward cant of nine degrees from the vehicle center line. The retrorockets impart a retarding force to the S-IB stage to ensure complete S-IB/S-IVB stage separation and preclude the possibility of stage interactions. The retrorocket firing command is given simultaneously with the separation command; however, a short time delay between the release of the S-IVB from the S-IB stage and retrorocket ignition ensures that the S-IVB stage propellants will remain settled in the aft tank sections.

The S-IB/S-IVB ullage rockets and retrorockets are adequate for use in the Saturn IB/Centaur application.

Table IV-2. S-IB/S-IVB Staging System

	Ullage	Retro
Propellant	Solid	Solid
Manufacturer/Model Number	Thiokol/TX-280	Thiokol/TE-29-1B
Nominal Thrust, 70°F	3460 lbs.	35,600 lbs.
Burn Time	3.94 seconds	1.5 seconds
Total Impulse	15,270 lb-sec	58,500 lb-sec

3. S-IVB/Centaur Staging System

An S-IVB Stage Retro System will be provided for the Saturn IB/Centaur vehicle as retro provisions are not included on the basic S-IVB vehicle. This involves new design.

A preliminary investigation has shown that four solid propellant rockets each delivering 5,500 pounds of thrust for 1 second will be adequate for the S-IVB/Centaur retro maneuver. The four retrorockets will weigh approximately 200 pounds. The optimum retrorocket locations will be determined by a detailed design study.

G. S-IVB PROPULSION COMPONENT QUALIFICATION

Preliminary evaluation has shown that the environmental levels experienced on the S-IVB stage of the Saturn IB/Centaur launch vehicle does not exceed the environmental specification levels of the basic Saturn IB vehicle. Therefore, no component requalification is required.

SECTION V. CENTAUR STAGE PROPULSION SYSTEMS

This section presents the results of a study of the Centaur propulsion system as utilized in the Saturn IB/Centaur launch vehicle configuration. The intent of this activity was to evaluate the adequacy of the various subsystems and identify those areas which may require modification. A brief description of each subsystem is given.

A. RL10A-3-3 ENGINE SYSTEM

Main propulsive thrust is provided by two Pratt and Whitney Aircraft (P&WA) RL10A-3-3 liquid rocket engines rated at 15, 000 pounds of thrust each with a specific impulse of 444 seconds. The engines are fixed thrust, gimbal mounted and capable of multiple starts in space. Each engine includes assorted pneumatic, hydraulic, and solenoid operated valves, turbopumps, thrust chamber, thrust control valves, and associated propellant and pneumatic lines. Oxidizer and fuel centrifugal pumps are geared to a turbine that is driven by gaseous hydrogen. The hydrogen fuel passes through a two-stage pump, through the regenerative cooling tubes of the thrust chamber wall where it is vaporized, through the turbine, and then through the injector to the combustion chamber. The oxygen passes through a single-stage pump and then through the injector to the combustion chamber. Constant chamber pressure is maintained by using it as a reference for a bypass valve which can divert some of the gaseous hydrogen around the turbine directly to the injector. A nominal Isp rating of 444 seconds is achieved by a nominal 5:1 mixture ratio, a 400 psia chamber pressure and a nozzle area ratio of 57:1. Engine controls are operated by a vehicle-borne helium supply. A hydraulic pump drive pad is provided on each of the engine turbopumps. A data summary for the engine is presented in table V-1.

Early Centaur development vehicles utilized the P&WA RL10A-3-1 engine. The uprated engine model prototype is currently planned to be effective for the Atlas/Centaur launch vehicle 8 (AC-8), and operational on vehicles AC-12 and subsequent. Main differences between the two engines are summarized in table V-2.

No modifications to the basic engine system are required for Saturn IB/Centaur launch vehicle applications.

Table V-1. RL10A-3-3 Engine Data Summary*

*REF: Pratt & Whitney Aircraft
"Preliminary RL10A-3-3
Model Specification Number 2265," 25 August 1964.

PARAMETER	VALUE
PERFORMANCE (At Standard Inlet Conditions)	
Thrust (Vac)	15,000 ± 300 lb
Specific Impulse, Nominal	444 sec
Specific Impulse, Minimum (3σ)	439 sec
Mixture Ratio, Nominal (Factory Setting)	5.0 ± 2.0%
Acceleration Time (From Start to 90% Maximum Thrust)	2 sec maximum
Start Impulse (0 to 95% Thrust and 81° F)	1800 (± 1000) lb-sec
Shutdown Time (From Removal of Start Signal to 5% Rated Thrust)	0.15 sec max.
Shutdown Impulse	1215 (± 150) lb-sec
Nominal Running Time	470 sec
Number of Starts During Service Life	Twenty
Service Life	2820 sec
Thrust Vectoring (Gimbal Range)	± 4.0° (square pattern)
Geometric Thrust Axis Location (From Gimbal Point)	± 1/16 inch
DESCRIPTIONS AND DIMENSIONS:	
Type - Regeneratively-cooled turbopump-fed liquid-oxygen, liquid-hydrogen rocket engine	
Maximum Engine Diameter (At Room Temperature)	39.7 inches
Maximum Engine Length (At Room Temperature)	70.1 inches
Maximum Radial Projection from Centerline	20 inches
Nozzle Area Ratio	57:1
WEIGHT:	
Dry Weight, Including Standard Equipment, Shall not Exceed	300 lbs
ACCESSORY DRIVE:	
Speed (Nominal)	11,400 rpm
Torque	20 lb-in

Table V-2. Comparison of RL10A-3-3 and RL10A-3-1

Parameter	RL10A-3-3	RL10A-3-1
Thrust Chamber Area Ratio	57:1	40:1
Nominal Specific Impulse	444 sec	433 sec
Nominal Chamber Pressure At Rated Thrust	400 psia	300 psia
Turbine	2-Stage Full Admission, Pressure Compounded	2-Stage Partial Admission Velocity Compounded
Fuel Pump	4 psi min NPSP, Increased Impeller Sweep	8 psi min NPSP
LOX Pump	8 psi min NPSP, Increased Impeller Diameter	15 psi min NPSP
Injector	Modified A-3-1 for Increased Performance	Std A-3-1
Thrust Control	Increased Strength Bellows	Std A-3-1
Propellant Lines	Increased Wall Thickness Venturi and Main Fuel Shutoff Valve (MFSOV) Line	Std A-3-1

B. CENTAUR ENGINE CHILLDOWN SYSTEM

Engine pump chilldown is required prior to initiation of main pump flow to prevent the occurence of pump stall or combustion instability during the start transient. The system considered for Saturn IB/Centaur employs the essential features of the Atlas/Centaur system. Vehicle-borne helium chilldown lines and supply and vent disconnect fittings, turbopump fittings, collector manifold, overboard dump line, and engine supplied chilldown valves comprise the system. Some new design is required in this system as a result of the new shroud and S-IVB/Centaur interstage structure.

Chilldown occurs in two operations, ground and flight related. Ground chilldown is accomplished by flowing cryogenic helium at flowrates up to 10 lbs/minute and temperature below -390°F through the LH_2 pumps. Control parameters are: 1) hydrogen pump surface temperature which must be held below -360°F, and 2) helium supply temperature which must be held below -390°F; both for a 10 minute period prior to launch. Helium reclamation (not currently required) is recommended. Inflight chilldown occurs by 1) prestart LO_2 flow which flows through the pump and is vented overboard through the engine injector and 2) prestart LH_2 flow which circulates through both pump stages and is dumped overboard through a vent system.

Inflight venting operation requires close control and sequencing of events relative to times when vent gas ignition may occur. Dumped hydrogen vapors must be ducted beyond the 260-inch S-IVB stage envelope.

Overall propulsion chilldown sequence includes boost pump chilldown and propellant feed system chilldown. The boost pumps are started before the initiation of the main engine chilldown, and propellants are circulated through the feed lines and tanks in a closed loop. Recommended events sequences are as shown in table V-3.

Other methods may be used to accomplish engine chilldown that require a lesser penalty associated with the dumped vehicle propellants. These may include propellant circulation concepts, usage of pump low thermal conductivity internal coatings, etc. The method outlined above was selected, however, because of its current use in the existing Centaur program.

Table V-3. Propulsion Chilldown Sequence

FIRST BURN	EVENT
MES – 40 seconds	Boost pumps start signal
MES – 8.5 seconds	S-IVB cutoff signal
MES – 5 seconds	(1) Prestart signal (2) Main engine pump valves open (3) Engine bleed valves to cooldown position
MES	(1) Main engine start signal (2) Fuel prevalves open (3) Cooldown valves to bleed position
MECO	(1) Main engine cutoff signal (2) Main engine pump valves close (3) Fuel prevalves close (4) Cooldown valves to vent position
SECOND BURN	
MES – 25 seconds	Boost pumps start signal
MES – 5 seconds	(1) Prestart signal (2) Main engine pump valves open (3) Engine bleed valves to cooldown position
MES	(1) Main engine start signal (2) Fuel prevalves open (3) Cooldown valves to bleed position
MECO	(1) Main engine cutoff signal (2) Main engine pump valves close (3) Fuel prevalves close (4) Cooldown valves to vent position

C. CENTAUR PNEUMATIC SYSTEM

The pneumatic system provides a gas source to satisfy the pressurization, pneumatic control, and purge requirements of the Centaur vehicle as shown in tables V-4 and V-5 for the existing Centaur. Centaur requirements in Saturn IB applications will not change significantly from Atlas/Centaur requirements, although several hardware changes will be required due to the shrouded configuration.

Table V-4. Pneumatic System Supply Requirements (Ref AC-12) *

Function	Pressure (psig)	Temperature (F)	Flowrate (lb/min)	Time (min)	Quantity (lb)	Remarks
LH_2 tank pressurization and purging	See table V-5 See table V-5 See table V-5 See table V-5	Ambient Ambient Ambient Ambient	3 6 3 22	As req. 6 15 30	60 180 45 645	GHe normal supply GHe emergency supply GHe purge pre-fill $WN_2 \leq 10\%$ $WO_2 \leq 3\%$ GN_2 purge-post drain $WH_2 \leq 4\%$
LOX tank pressurization and purging	See table V-5 See table V-5	Ambient Ambient	3 6	As req. 30	60 180	GHe normal supply GHe emergency supply
Fill and drain valve Purge and actuation	800	Ambient	0.005	As req.	8	GHe
Engine ground chilldown	20 25-75	Ambient -390	5.2 10 max.	10 60-15	52 120	GHe for purge GHe for chilldown
Helium supply pressurization	1500 2400 3345	Ambient 71 max.	0.3 max.	195 max. 15 max. 60 max.	19	GHe maximum temperature 152°F during charging and 120°F at launch

* Helium Specification Bureau of Mines Grade A
Nitrogen Specification MIL-P-27401

Table V-5. Tank Pressurization Requirements (Ref AC-12)

Vehicle Operating Condition	Tank Pressure (Tolerances ± 1 psi) (psig)	
	LO_2 Tank* ($376\ ft^3$)	LH_2 Tank ($1267\ ft^3$)
Stand-by	7 to 13	2 to 9
LO_2 chilldown	13 to 25	2 to 9
LO_2 tanking	13 to 25	2 to 9
LH_2 chilldown	13 to 21	2 to 14
LH_2 tanking	13 to 21	2 to 14
Launch	13 to 21	2 to 9

*Minimum allowable LO_2 tank pressure is 1 psi in excess of the static pressure at the LH_2 aft dome.

The major subsystems are as follows:

1. Umbilical Disconnect Panels

Two or three umbilical disconnect panels will be required to accommodate the normal gas services (LH_2 and LO_2 tanks ground pressurization, helium storage pressurization, and purge), propellant tanks fill/drain and vent services, and electrical and instrumentation functions. Pneumatic actuation at liftoff will be supplied by ground pneumatic pressure. Inflight actuation, if required, could be provided pneumatically by the vehicle-borne helium storage. The latching mechanism would be contained in the ground half for liftoff separation and in the vehicle half for any required inflight separation. Alternate disconnect schemes are discussed in Section V, K.

2. Engine and Fuel Tank Insulation Purge System

The engine purge requirements existing in the current Atlas/Centaur engine system will not change due to Saturn IB applications since the conditioned engine compartment prior to flight will be about the same. The purge requirements for the tank insulation will be reduced or eliminated since the insulation panels are not jettisoned in flight and since the Centaur/shroud annular space will have preflight environmental conditioning. Incorporating a permanent bonded superinsulation concept would definitely preclude purging. The purging connection is a 1/2-inch disconnect fitting.

3. Intermediate Bulkhead Vacuum System

The intermediate bulkhead vacuum system consists of the bulkhead annular space, check valve, and tubing open to atmosphere. The system "cryopumps" to high vacuum when LH_2 is loaded, thereby reducing heat transfer to a very low level. The vacuum pumping system, currently used in the Atlas/Centaur as a backup evacuation system only, will not be required in the Saturn/Centaur program.

4. Helium Storage System

The helium storage system is provided to supply helium gas for propellant tank prestart pressurization, engine control, peroxide storage expulsion (two spheres), bleed flow, and for pneumatic actuation of any new vehicle-borne disconnect panels requiring inflight separation. The existing system has a storage sphere volume of 4650 cubic inches and an additional 1000 cubic inches in the associated lines. Initial charge pressure is 3000 psi at ambient temperature. Final pressure must exceed 450 psi sufficiently to ensure proper operation of the 450 psi engine controls regulator. Added pneumatic requirements in the Saturn IB/Centaur configuration, may necessitate an increased storage capacity, to be accomplished by increasing initial storage pressure or increasing storage volume. Initial pressurization of the sphere is accomplished through a 1/2-inch disconnect fitting.

5. Pneumatic Control System

The pneumatic control system includes the current engine controls and peroxide storage regulator, relief valves, filters, checkout fittings, tubing, and new hardware, as required to supply pneumatic actuation pressure to new umbilical disconnect panels for inflight separation. Such new hardware would consist of a solenoid valve and tubing located to utilize engine controls pneumatics. The modified pneumatic control system is shown schematically in figure V-1. Alternate umbilical disconnect schemes are discussed in Section V, K.

6. Propellant Tank Pressurization System

The propellant tank pressurization system maintains safe pressure levels in the propellant tanks while on the ground during standby, propellant loading and topping, propellant dumping, and tank purging, and provides a short burst of pressurization gas prior to boost pump starts in flight. Hardware elements consist of a 1/2-inch disconnect fitting, tubing, check valve, flow restrictor, and solenoid valve in each tank supply system, as well as a filter and helium storage sphere. New flow ducting is required to extend from the Centaur skin line to the 260-inch diameter shroud.

7. Propellant Tank Vent System

The propellant tank vent system consists of a single solenoid-operated vent valve for the LO_2 tank, two solenoid-operated vent valves for the LH_2 tank, 3-inch vent lines, and 3-inch vent disconnect fittings. All vent valves have relief

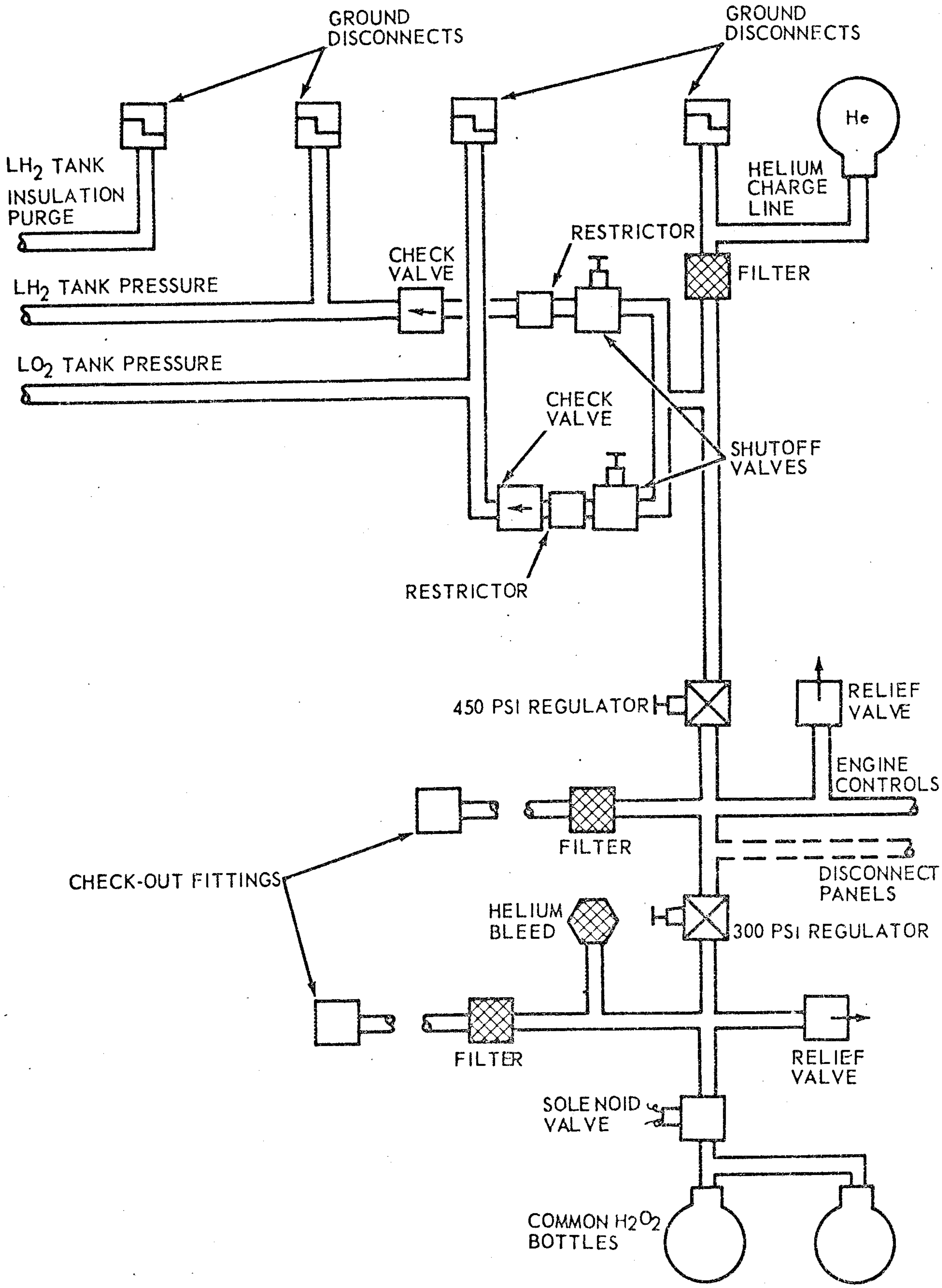


Figure V-1. Pneumatic Control System Schematic features. Each propellant tank must vent beyond the 260-inch diameter shroud on the ground and in boost flight up to the time of shroud separation or staging. After this time venting will occur at a new location and must incorporate non-propulsive features.

D. CENTAUR PROPELLANT SYSTEM

The main engine propellant feed system consists of the oxidizer and fuel centrifugal boost pumps with their hydrogen peroxide supply system and the bifurcated oxidizer and fuel propellant ducts which connect the individual boost pumps with the two main engines. No anti-vortex baffles are used, although boost pump inlet vanes are included. Propellant tank fill and drain lines and disconnects are also normally considered to be a part of the propellant feed system.

Each boost pump unit is submerged in the propellant tank outlet sump of each tank. The pumps raise the propellant pressures from the low values in the tanks (LO_2:30 psia; LH_2:20 psia) to the higher pressures required at the main engine turbopump inlets (LO_2 net positive suction pressure (NPSP): 8 psi; LH_2 NPSP: 4 psi). Liquid oxygen boost pump speed is approximately 3600 rpm and is driven by the turbine through a 9.1:1 gear reduction. Liquid hydrogen boost pump speed is approximately 7600 rpm, driven through a 5.97:1 gear reduction. Nominal steady state head rise for these two operating conditions is approximately 33 psi and 16 psi for the LO_2 and LH_2 boost pumps, respectively. Approximate NPSP requirements for the boost pumps are LO_2: 1 psi; LH_2: 0.1 psi. Hardware elements include the boost pumps, turbine drives and gear trains, catalyst beds, and decomposition chambers, heating elements, and overspeed sensing and control systems. The heating element is a 40 watt, 28 vdc, continuous power element which maintains high relative temperature for rapid start. The speed control system prevents turbine overspeed and provides high initial peroxide flow to decrease start transient time.

The hydrogen peroxide propellant supply system uses regulated helium pressure (300 psia) to collapse the flexible bladder and thus force the mono-propellant out through a perforated standpipe. The central storage system for the hydrogen peroxide system requires some modification to the reference Atlas/Centaur-12 (AC-12) storage system to handle the propellant quantities identified in figure V-4. The peroxide is expended through boost pump system and auxiliary propulsion reaction control system usage. Total nominal expended peroxide is 443 pounds. Allowing 45 pounds for performance margin, a total capacity of 488 pounds, or 9715 cubic inches is required. A second storage sphere of the existing AC-12 configuration (4870 cubic inches) is added bringing the total usable volume to 9740 cubic inches which is adequate for the needs outlined. Temperature conditioning is provided for the storage spheres during terminal ground operations by a manually controlled 28 vdc heater blanket. Supply line temperatures are conditioned within a range of 40°F to 120°F by constant power line heaters. Expulsion pressure is controlled by a regulated helium supply solenoid valve and by a hydrogen peroxide dump valve as shown in figure V-2.

Additional modifications include new ducting in the Centaur-to-shroud interface area for all propellant systems.

E. CENTAUR PROPELLANT LEVEL INDICATING SYSTEM

The propellant level indicating system (PLIS) is used during propellant loading to sense the mass of propellants in each tank. The masses sensed by the transducers in terms of 0 to 100 per cent mass are transmitted electrically through a vehicle umbilical to ground support equipment control and monitor equipment used during tank filling operations. Discrete level sensing occurs at 95, 99, and 100 per cent load points. Accuracy (3σ) of the loaded mass, considering tank volume, propellant density, and losses, is expected to be known within ± 3 per cent for the LH_2 and ± 0.5 per cent for the LO_2. The transducer employed for the discrete level indication is a platinum wire grid which forms one resistance element in a bridge circuit. The transducers are mounted in pairs inside an inertia tube. The LH_2 inertia tube is supported from the forward tank dome structure, and the LO_2 inertia tube is mounted on the propellant utilization sensing assembly. Detailed propellant loading system requirements are shown in table V-6. No changes are required on this basic system.

F. CENTAUR PROPELLANT UTILIZATION SYSTEM

A propellant utilization (PU) system is provided to minimize propellant outage (outage: residual weight of one propellant, due to mixture ratio variation, at depletion of the other propellant) which results from dispersion due to loading, engine performance, etc.

The PU system performs this function by comparing the amount of propellant in each tank and metering the flow of oxidizer to the engine. Engine mixture ratio variations across a relatively wide range, ± 10 per cent, are allowed for control purposes since specific impulse effect on performance in this range is offset by the mass ratio effect on the overall performance. Closed loop operation occurs from shortly after engine start to just before engine shutdown. Maximum outage (+ 3σ) is reportedly less than 0.5 per cent.

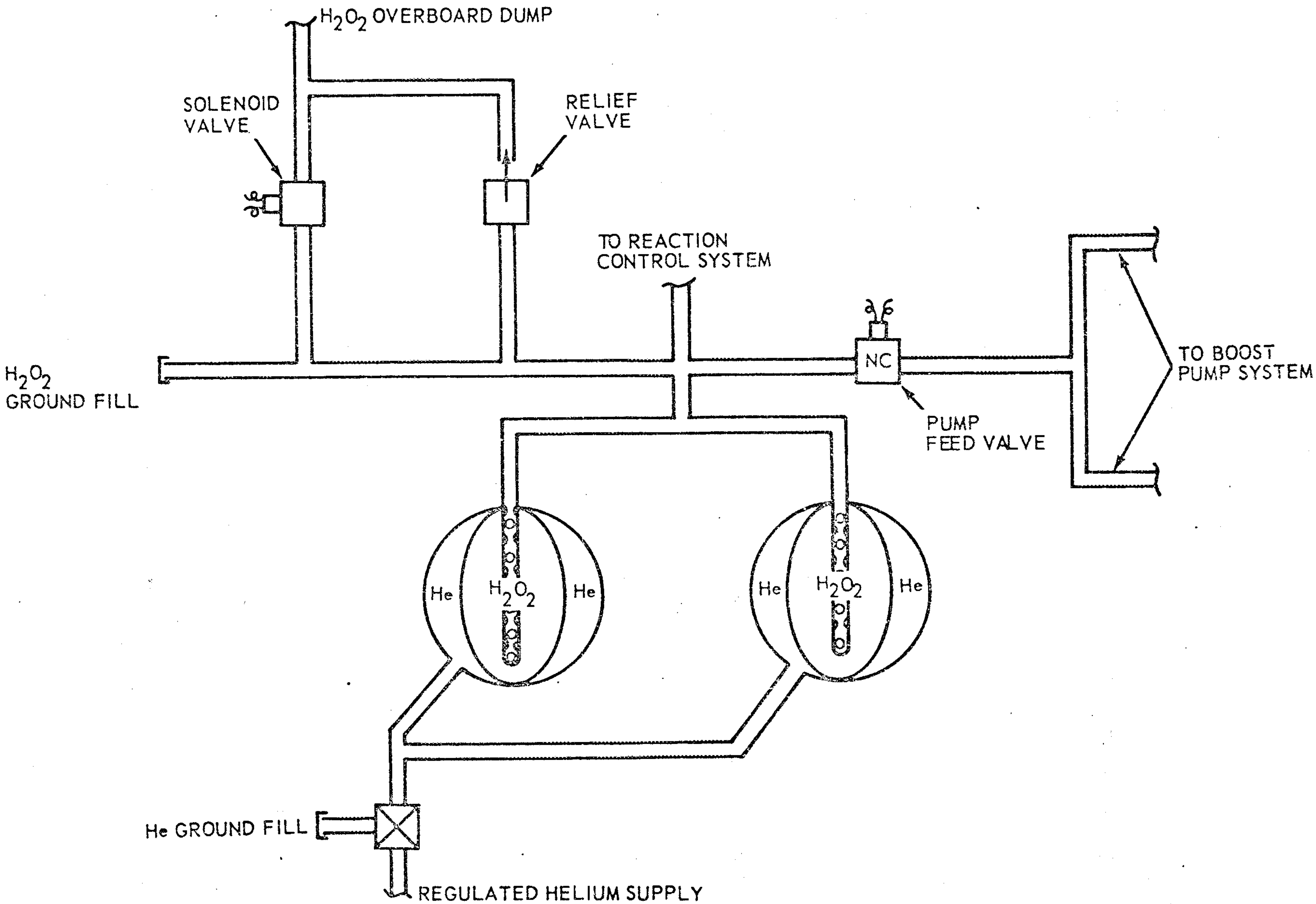


Figure V-2. Hydrogen Peroxide Supply System Schematic

TABLE V-6 PROPELLANT TRANSFER SYSTEM -

MANUAL CONTROL REQUIREMENTS REF. (Ref. AC-12)

	Back Pressure (psig)	Temperature (°R)	Flow Rate (lbs/min	Time (mins)
LIQUID OXYGEN* (Load ∽ 25,000 lbs)				
Chilldown	13 (± 1) to 25 (± 1)	175 - 178	0 - 4140	10
Fill to 95%	13 (± 1) to 25 (± 1)	175 - 178	4140 max	6
Fill, 95% to 100%	13 (± 1) to 25 (± 1)	175 - 178	0 - 4140	3
Topping	13 (± 1) to 25 (± 1)	175 - 178	0 - 4140	10 min
Drain	13 (± 1) to 25 (± 1)	175 - 178	2760	
LIQUID HYDROGEN* (Load ∽ 5,000 lbs)				
Chilldown **	2 (± 1) to 14 (± 1)	36.7 - 39.4	0 - 562	3
Fill to 95%	2 (± 1) to 14 (± 1)	36.7 - 39.4	562 max	9
Fill, 95% to 100%	2 (± 1) to 14 (± 1)	36.7 - 39.4	562 - 5.62	3
Topping	2 (± 1) to 9 (± 1)	36.7 - 39.4	562 - 5.62	5 min
Drain	2 (± 1) to 9 (± 1)	36.7 - 39.4	170 min - 562 max	30 max

* - Specifications
Liquid Oxygen MIL-P-25508(A), Max. Particle Size 175 microns
Liquid Hydrogen MIL-P-27201(A), Max. Particle Size 175 microns

** - Initiated after LO_2 Load is at 50% Level.

Major system hardware elements are the contoured sensors which provide geometry compensation, an electronic package, and a servo positioner mounted on each engine mixture ratio control valve. This system is also used for mass indication during propellant loading operations on the ground. Electrical signals proportional to propellant mass are fed through a vehicle umbilical to ground monitoring equipment in the same manner as the normal PLIS signals. No changes are required in this system.

G. CENTAUR AUXILIARY PROPULSION SYSTEMS

Auxiliary or secondary propulsion systems are required on the Centaur stage to perform the following basic functions listed in table V-7.

Table V-7. Centaur Auxiliary Propulsion Requirements

Function	System Design Status
H_2O_2 Systems	
S-IVB/Centaur Staging	Exists (AC-4)
Attitude Control	Exists (AC-12)
Propellant Settling	To be modified (AC-4)
Centaur/Payload Separation System	New
Shroud Separation System	New
Pegasus Station Keeping System (Optional)	New

The main elements of the proposed auxiliary propulsion system are the hydrogen peroxide reaction control systems which satisfy staging, attitude control, and propellant settling requirements. Supplementary propulsion systems to satisfy a shroud separation-requirement and a hypothetical Pegasus station keeping function have also been investigated.

1. Hydrogen Peroxide Systems

The basic peroxide reaction control system is similar to the AC-4 system in that it consists of four 50-pound thrust nozzles for propellant settling and staging, six attitude control nozzles (four rated at 1.5 pounds thrust for yaw and roll control, and two rated at 3 pounds thrust for pitch control), and two coast duration low thrust nozzles (modified for 3 pounds of thrust from the AC-4 2-pound thrust), and uses the same 90 per cent hydrogen peroxide pressure-fed monopropellant. These nozzles are all located on the LO_2 tank aft bulkhead as shown in figure V-3.

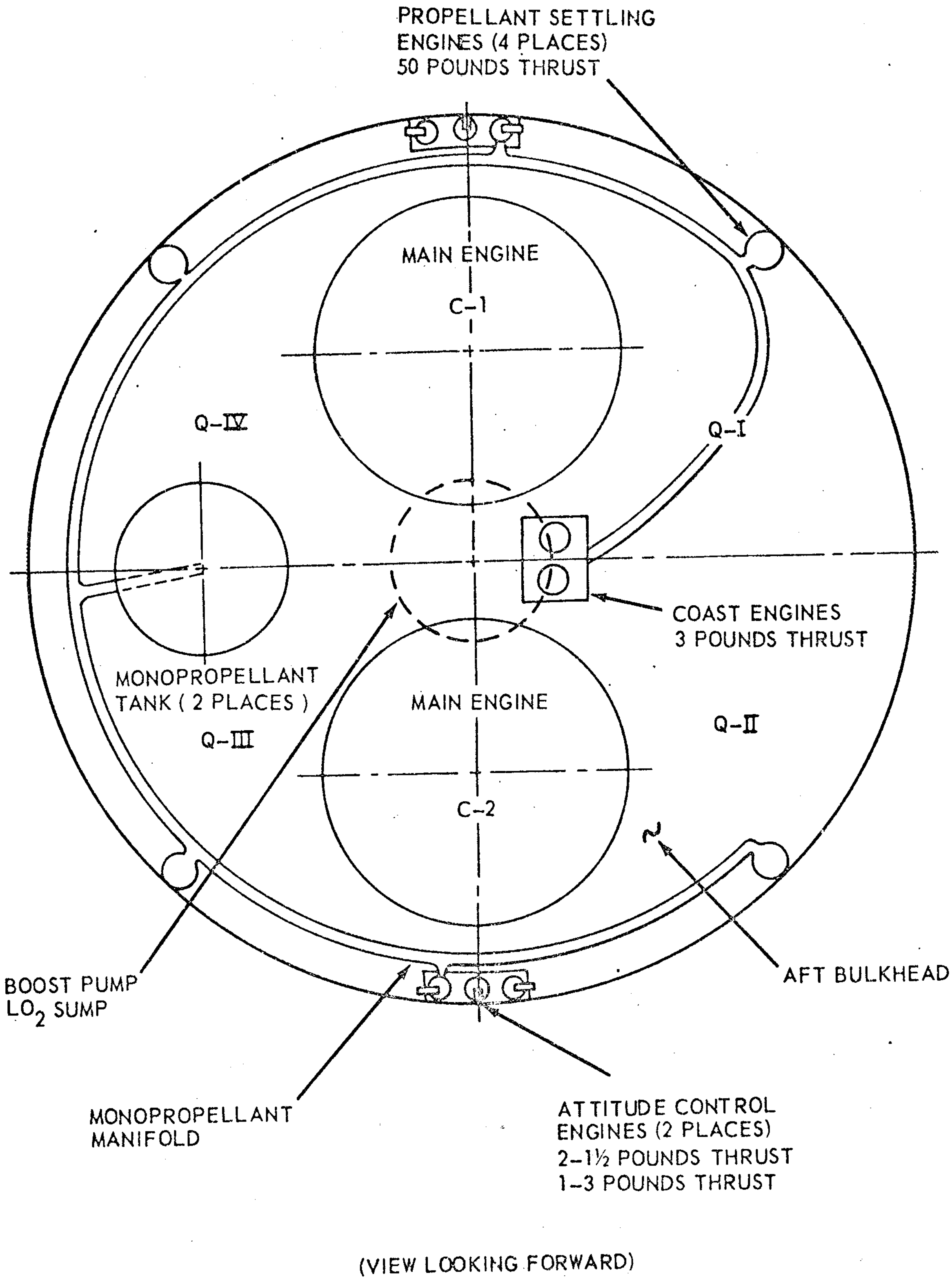


Figure V-3. Peroxide System Arrangement

The two coast phase nozzles have been modified for higher thrust to satisfy a Bond number criterion which indicates a requirement for a minimum steady 10^{-4} G_0 acceleration to maintain main stage propellant orientation (for venting purposes) during coast. The four high thrust (50 pounds of thrust each) nozzles are used to settle the main tank propellants after main engine shutdown and to ensure a settled condition prior to engine start.

Hydrogen peroxide is expended in several systems including the boost pump system and several modes of auxiliary propulsion system operation, as shown in figure V-4. This figure depicts approximate sequencing of the many system operations with respect to the Centaur main propulsion events for a hypothetical mission which includes an entire earth orbit coasting phase.

Flow control of the monopropellant is provided by solenoid valves which are integral with the reaction control system nozzles. Supply pressure is approximately identical with the storage pressure.

2. Centaur/Payload Separation System

Both Centaur/Payload separation and Centaur retro-maneuver are required to ensure ready payload identification from ground tracking stations and to prevent a collision of Centaur and the payload after separation.

The retro-system modules and stage mounting hardware should be designed for optimal dynamic performance during the separation process and for maximum reliability. Adequate structural clearance must be demonstrated analytically for a one retro engine out condition. Dynamical analysis of this nature, the normal starting point in retro system design, is strongly influenced by stage design configurations. A separation acceleration of 0.5 G_0, a burning time of 1.5 seconds, a nozzle cant angle of 30° off vehicle centerline, and an inert Centaur mass of 6000 pounds were assumed for initial approximation in this study. Weight of the solid rockets was then calculated to be 44 pounds. Total thrust required, according to the assumptions, is 3500 pounds.

3. Shroud Separation System

The shroud is cut longitudinally into two clam-like segments by a linear shaped charge. Separation thrust is supplied by cold-gas (nitrogen) jets from gas stored at 3000 psi in two 13 1/2-inch diameter spheres located in the nose of the shroud.

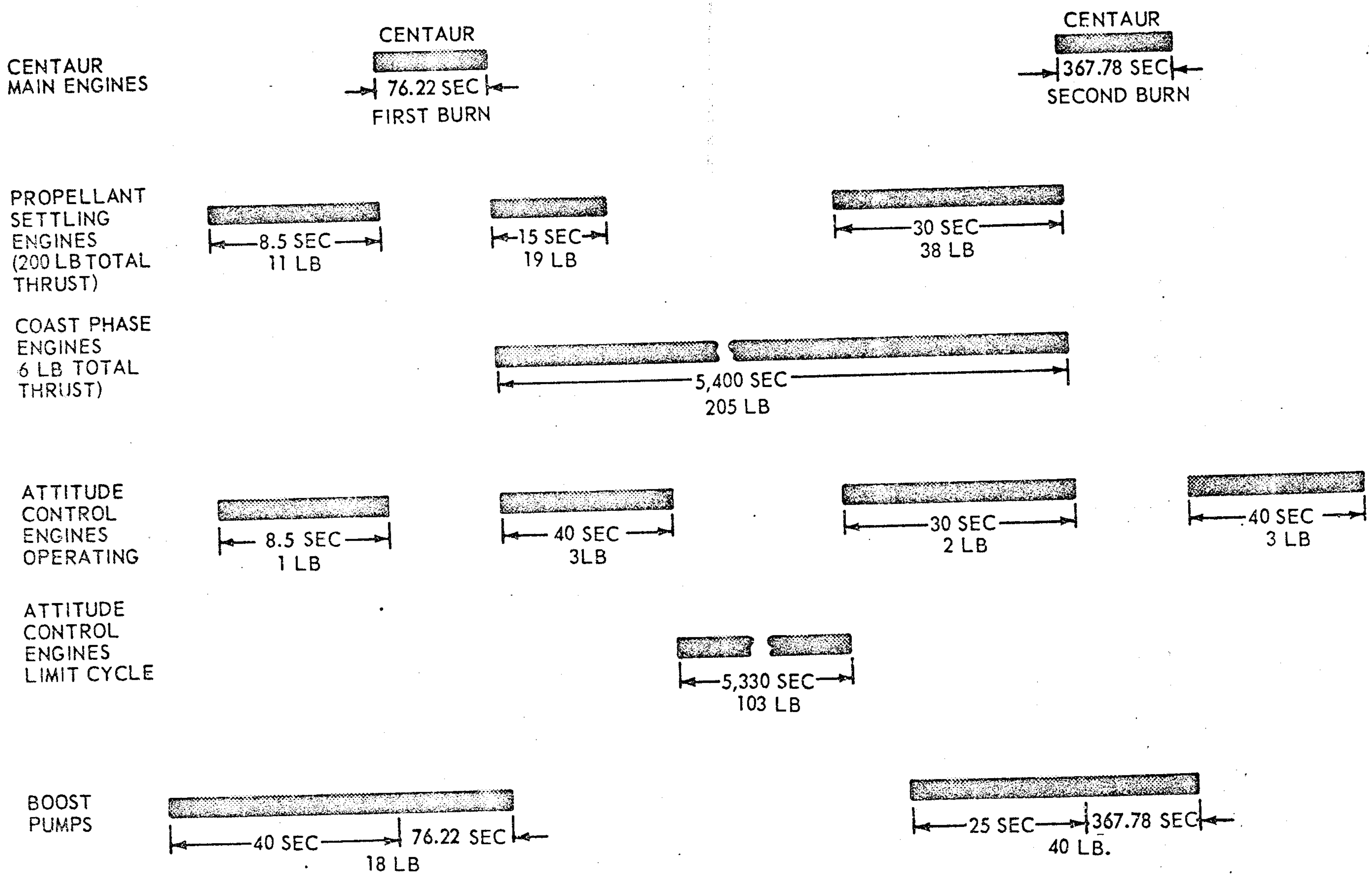


Figure V-4. Hydrogen Peroxide System Requirements

This system has a disadvantage of high weight. An alternate method of separation was investigated and some of the pertinent technical details are presented in the following paragraph.

Centaur and payload shroud can be positively separated by employing small solid rocket motors positioned and sized so that high reliability and separation clearance are assured. For this purpose, a solid rocket thrust of 200 pounds with a burning time of 1.5 seconds was selected. Eight motors on each of the two shroud clamshell segments, four forward and aft, provide adequate shroud separation clearance for a one-rocket-out (per segment) condition. For this computation, the shroud was assumed to weigh 5600 pounds, separation was assumed to occur at 350,000 feet, and Centaur acceleration was assumed to be 0.8 G_o. The weight of this system is estimated to be 80 pounds, which is at least 35 per cent lighter than the cold gas system.

4. Pegasus Station Keeping System

A preliminary investigation has been conducted into an auxiliary propulsion system to provide station keeping impulse for the combined Centaur/Pegasus in circumlunar orbit. Basic assumptions were:

(1) Orbital period = 1/2 lunar month

(2) ΔV per orbit = 60 ft/sec

(3) Total Service Life = 1 year

Using the equation

$$\Delta V = G_o \, I_{SP} \ln \left[\frac{M_I + M_p}{M} \right]$$

where

M_I = Inert mass

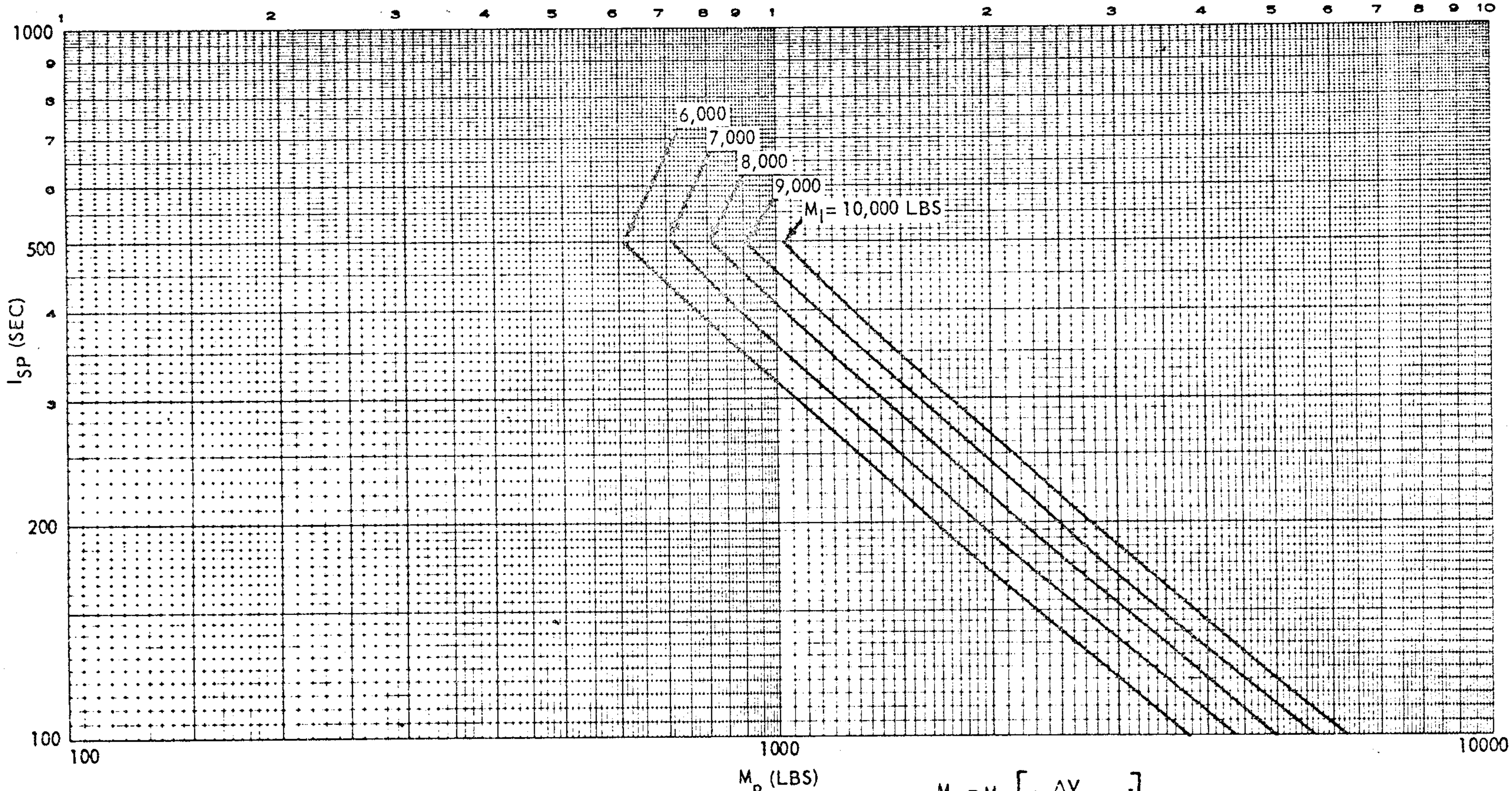
M_p = Impulse propellant mass

I_{SP} = Specific impulse

G_o = 32.2 ft/sec^2

ΔV = Velocity increment,

the results shown in figure V-5 were calculated.



$$M_p = M_I \left[e^{\frac{\Delta V}{G_o I_{sp}}} - 1 \right]$$

ΔV = 1560 FT/SEC

G_o = 32.2 FT/SEC^2

Figure V-5. Station Keeping Propulsion Requirements

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If the inert mass in orbit for the Centaur/Pegasus combination is 8000 pounds, the total impulse required for station keeping is approximately 400,000 pounds-seconds. For comparison, the total impulse of the Centaur main propulsion system is approximately 13,200,000 pound-seconds and that of the current Centaur (AC-12) attitude control system approximately 25,000 pound-seconds. The propellant mass and weights of the associated system hardware are present in table V-8 for three Isp regimes.

H. CENTAUR PROPELLANT SLOSH DYNAMICS

Propellant dynamic slosh modes are of interest at any time during vehicle flight because of the possible influences on vehicle control systems. A brief study has been made of the slosh resonances of the Centaur propellants during the coast phase. A constant thrust of 6 pounds is applied to the vehicle during coast to maintain the propellants in a bottomed condition after initially settling with a 200 pound thrust.

Results of the study indicate LH_2 tank slosh frequencies of approximately 0.01 cps and 0.02 cps for the lowest unsymmetrical and symmetrical modes, respectively. The LO_2 slosh frequency approximations are 0.005 cps and 0.01 cps for unsymmetrical and symmetrical modes. These numbers indicate a relatively strong resonance may exist at 0.01 cps. To preclude this condition, the incorporation of an anti-slosh baffle in the LH_2 tank is recommended. Existing LO_2 tank internal engine support and thrust structure should provide some damping in that tank.

I. CENTAUR HYDRAULIC SYSTEM

The Centaur hydraulic system provides the mechanical force required for engine nulling and steering checks prior to main engine ignition and for engine gimballing during powered flight. Each engine has a self-contained hydraulic system consisting of a power package, two servo-valve actuator assemblies, connecting tubing, a manifold assembly, and miscellaneous other hardware including thermostats, mounting hardware and instrumentation. The power package includes a high pressure (1000 psi) engine driver pump which operates during main engine operation, a low pressure (80 psi) electric motor driven pump which operates during prestart nulling and steering checks and which can provide a thermostatically activated hydraulic fluid flow for temperature control when required. System servicing is a manual operation, with mechanical interfaces provided for ground pressurization and return lines. No modifications should be required in this system for use in the Saturn IB/Centaur vehicle configuration.

Table V-8. Centaur Station Keeping Auxiliary Propulsion System Weight Summary

Isp	Propellant	M_P (Fig. 1) (lbs)	$M_{Hardware}$ (Approximately) (lbs)					M
			Storage System (Pressure-Fed)	Pressurization System (Stored GHe)	Insulation System (Superinsulation)	Engine System	Plumbing & Misc.	Total (lbs)
158	H_2O_2	2900	80	85	40	50	35	3190
308	N_2O_4/N_2H_4	1370	50	50	40	50	35	1595
413	O_2/H_2	1000	70	145	90	50	35	1390

J. CENTAUR PROPELLANT TANK INSULATION

Propellant tank insulation is required for thermal protection of the Centaur stage cryogenic propellants, liquid hydrogen and liquid oxygen. A type of insulation similar to the existing Centaur insulation was assumed for this purpose because of its current development status relative to projected Saturn IB/Centaur initial launch dates.

The assumed insulation weighs approximately 1,450 pounds. Helium purging of the insulation panels will be required to prevent air or water vapor from condensing and causing a heat conduction short. Purge requirements are reduced from the Atlas/Centaur requirements because the panels will not be separated in flight and because the Centaur will be enshrouded during the aerodynamic heating portions of boost flight.

At a later date in the Saturn IB/Centaur program, incorporation of a much lighter weight type of heat barrier, a so-called "super-insulation," may be possible. Preliminary investigation indicates a "light-weight insulation" weight of 200 pounds is feasible. Detailed analytical studies must consider actual vehicle mission, hardware configuration, view factors, surface conditions, radiation sources, materials, etc. and will have the prime objective of increasing the stage mass fraction.

K. CENTAUR PROPULSION VEHICLE-BORNE UMBILICAL SYSTEM

Umbilicals are required as a part of each vehicle-borne fluid system to provide such services as propellant fill/drain, venting, chilldown, pressurization, purge, air conditioning, etc. A summary of umbilical requirements for existing Centaur fluid systems is presented in table V-9.

New design required for Centaur fluid systems will include: 1) new ducting to carry the normal disconnect points to the 260-inch diameter shroud positions; 2) grouping of the disconnects into panels which can be disengaged as assemblies; and 3) the possible incorporation of a second disconnect operation to occur at shroud separation or staging from the S-IVB.

A single-disconnect approach is advocated because of improved reliability over the dual-disconnect approach. In the single-disconnect approach, permanent hardware is provided between Centaur and the shroud disconnect point, a distance of 70 inches. Upon separation, the shroud flies free of the umbilical panel and support structure which remain with Centaur. An alternate single-disconnect method would allow disconnect nearer the Centaur and would require mechanically articulated retraction of the ground-half from the vehicle flight path.

L. CENTAUR PROPULSION COMPONENT QUALIFICATION

The Centaur environments in the Saturn IB/Centaur launch vehicle are reportedly comparable to those of the Atlas/Centaur launch vehicle. Therefore, no component requalification will be required. All new hardware elements must be qualified in the usual manner.

Table V-9. Centaur Fluid Systems Umbilical Requirements

Function	Location*	Size (Inches)	Type	Separation Time (Approximate)
LO_2 tank pressure	Aft boom, disconnect panel sta. 1771.7; Q-2, 28° 45' from Y	1/2	Lanyard**	Liftoff
GHe-LH_2 tank pressure	Aft boom, disconnect panel	1/2	Lanyard**	Liftoff
GHe-purge	Aft boom, disconnect panel	1/2	Lanyard**	Liftoff
GHe-storage pressure	Aft boom, disconnect panel	1/2	Lanyard**	Liftoff
GHe-engine childown	Aft boom, disconnect panel sta. aft; Q-2	3/4	Lanyard	Liftoff
LO_2 loading	Aft boom, on skin sta. 1798; Q-2, 30° from X	3	Pneumatic	Liftoff
LH_2 loading	Aft boom, on skin sta. 1872; Q-2, 25° from Y	3	Pneumatic	Liftoff
GH_2 vent	Forward boom, fin sta. 2014.5; Q-2, 25° from X	3	Lanyard	Liftoff
GO_2 vent (Boil-off valve: sta. 1764; Q-3, 30° from X)	Aft, on skin, sta. 1753; Q-1, 32° 45' from X	3	Overboard (No umbilical)	--
Engine childown vent	Aft, fin approx. sta. 1746; Q-2	--	--	Liftoff
Air conditioning	Aft, engine compartment, on skin sta. 1756.5; Q-2, 25° from X	--	Lanyard	Liftoff

Table V-9. Centaur Fluid Systems Umbilical Requirements (Continued)

Function	Location*	Size (Inches)	Type	Separation Time (Approximate)
Air conditioning	Forward, guidance and electrical	--	Lanyard	Liftoff
Air conditioning	Forward, payload	--	Lanyard	Liftoff
H_2O_2 servicing (2)	Aft	--	Manual	Pre-launch
Hydraulic system servicing	Aft	--	Manual	Pre-launch
Engine servicing	Aft	--	Manual	Pre-launch

* Referenced from figure V-6. Centaur station 444.30 is equivalent to Saturn IB/Centaur station 1771.7.

** Disconnected as a panel.

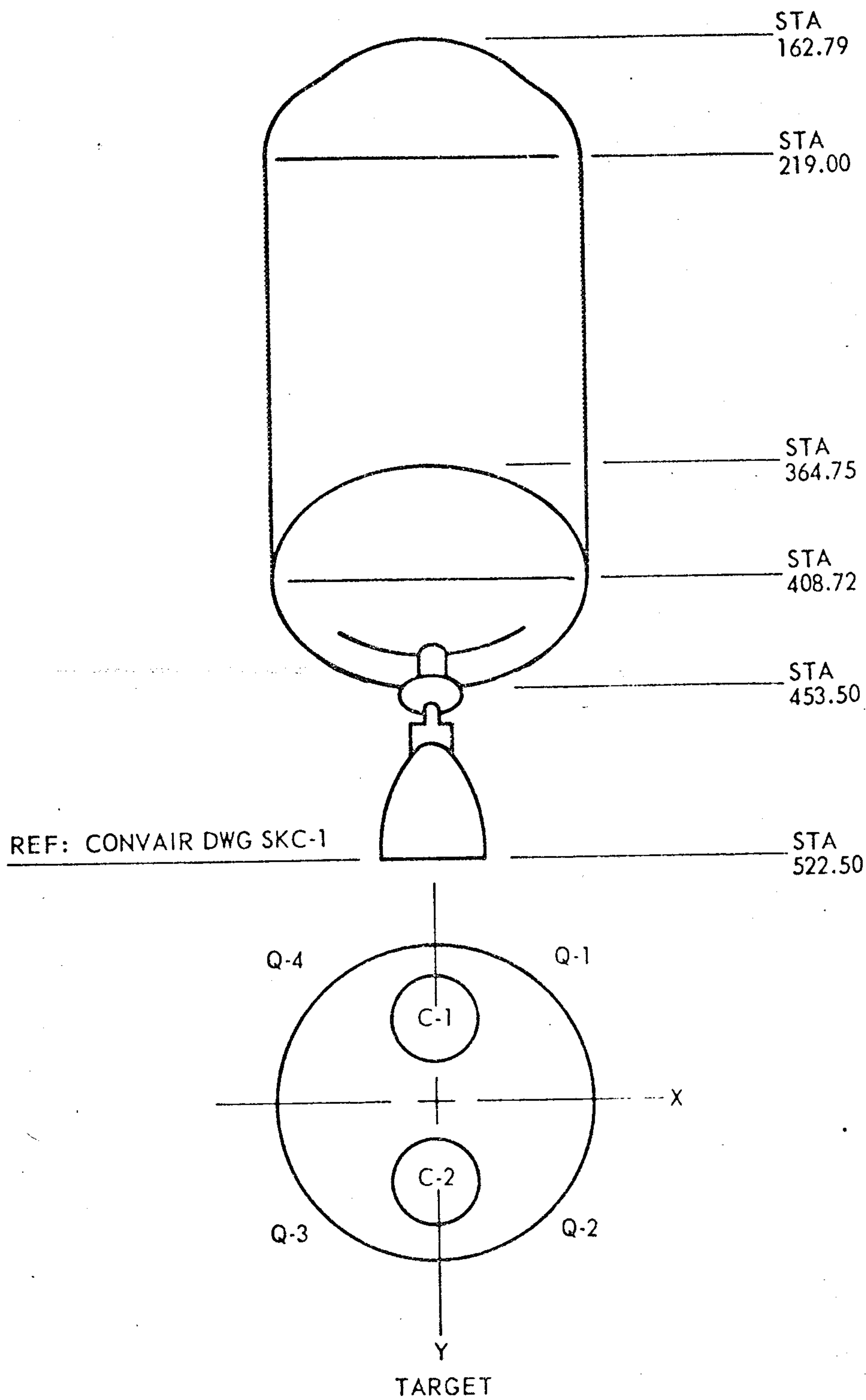

Figure V-6. Centaur Reference Schematic

SECTION VI. CENTAUR MECHANICAL GROUND SUPPORT EQUIPMENT

The requirement for additional Centaur-peculiar mechanical GSE for the existing Saturn IB Launch Complexes is discussed in the following paragraphs. Systems considered are propellant tank servicing, chilled helium equipment, hydrogen peroxide, hydraulics, pneumatics, and environmental control. A summary of the additional GSE is presented in table VI-1 and figure VI-1.

A. CENTAUR PROPELLANT TANK SERVICING

The Centaur LO_2 tank will be filled and replenished through the existing 3-inch vacuum-jacketed LO_2 replenishing line which is, in turn, suppled from the LO_2 replenishing facility. The Centaur LH_2 tank will be filled and replenished through a 4-inch vacuum-jacketed line connected to the existing 6-inch S-IVB liquid hydrogen filling and replenishing line at the base of the umbilical tower. During loading operations, the Centaur LO_2 tank must be maintained at approximately 34 psia and the LH_2 tank at approximately 21 psia. Since the LH_2 and LO_2 tanks have a common bulkhead, the LO_2 tank is always maintained at a pressure greater than the LH_2 tank.

Pressurization of the tanks is normally maintained by varying the propellant fill rate. Greater heat is gained by the propellant as the flow rate is decreased. This heat increases the propellant temperature and results in an increase in the saturation pressure. Excess pressure is relieved by propellant tank relief valves.

Since the LO_2 replenishing line is used to replenish both the S-IB and S-IVB stages, sufficient flow-rate latitude is not available to provide adequate control of the Centaur oxygen tank pressure. Therefore, a heat exchanger and temperature controls will be required to ensure delivery of LO_2 during loading at increased temperature. The propellant loading operations will be manually controlled at the blockhouse and achieved through the regulation of propellant flow control units located in the umbilical tower.

B. CENTAUR CHILLED HELIUM EQUIPMENT

The Centaur stage will require chilled helium gas at less than -390 F for engine chilldown. Supply equipment must be capable of providing chilled helium at 25 to 75 psig at a maximum flow rate of 10 pounds-per-minute for up to 60 minutes (120 pounds required). The S-IVB helium precool heat exchanger is currently required to supply a peak chilled-helium load of approximately 90 pounds-per-minute during the time span from T-2.2 minutes to T-1.2 minutes in the

Table VI-1. Additional Centaur-Peculiar Fluids System GSE

NAME	LOCATION	REMARKS
LH_2 flow control unit	Umbilical tower	Pneumatic control equipment for LH_2 flow and venting.
LH_2 transfer line	Umbilical tower	Routed up umbilical tower to flow control unit and across lower boom to vehicle from interface at S-IVB level.
LO_2 transfer line	Umbilical tower	Routed up umbilical tower to flow control unit and across lower boom to vehicle from interface at S-IVB level.
Hydrogen vent line	Umbilical tower	Routed from umbilical tower S-IVB interface point to LH_2 flow control unit, across upper boom, to vehicle.
LO_2 flow control unit	Umbilical tower	Pneumatic control equipment for LO_2 flow.
H_2O_2 transfer and control Unit	Service tower	Mobile equipment consists of storage tank, pump, flow meter, valves, and nitrogen pressurization system.
H_2O_2 and GN_2 Transfer lines	Service tower	Includes hand valves, filter, pressure cut-off, and manual connectors. Lines routed from H_2O_2 transfer and control system to vehicle.
H_2O_2 vacuum drying system	Service tower	Includes pumps, valves, pipes, LN_2 supply, and nitrogen purging system. Lines extend from pumping unit to vehicle.
Pneumatic distributor unit, primary	Pad	Primary regulation and distribution of facility helium and GN_2.
Pneumatic distributor unit, secondary	Pad	Secondary regulation and distribution of helium and GN_2.
Pressurization control unit	Pad	Controls helium pressurant to propellant tanks, storage bottle, and purges.
Nitrogen charge panel	Service tower	Controls nitrogen pressure for service requirements.

Table VI-1. Additional Centaur-Peculiar Fluids System GSE (Continued)

NAME	LOCATION	REMARKS
Umbilical tower pneumatic installation 1) LH_2 tank pressurization 2) LO_2 tank pressurization 3) He bottle pressurization 4) Actuation and purge 5) H_2O_2 pressurization 6) Engine service and checkout 7) Tower service	Umbilical tower	Service lines run from pressurization control unit pneumatic distributor unit (secondary) , up umbilical tower, to vehicle or tower service point.
Pneumatic checkout cart	Service tower	Mobile equipment.
Hydraulic system pumping unit and control panel	Service tower	Mobile equipment provides hydraulic service to Centaur.
Environmental conditioning lines	Umbilical tower	Routed up umbilical tower and across upper and lower booms to vehicle from Saturn systems in umbilical tower.
Cryogenic helium transfer lines	Umbilical tower	Routed up umbilical tower and across lower boom to vehicle from facility system.
Centaur booms	Umbilical tower	Upper and lower booms required for Centaur servicing.
Boom hydraulic actuation system	Umbilical tower	Provides boom retraction.

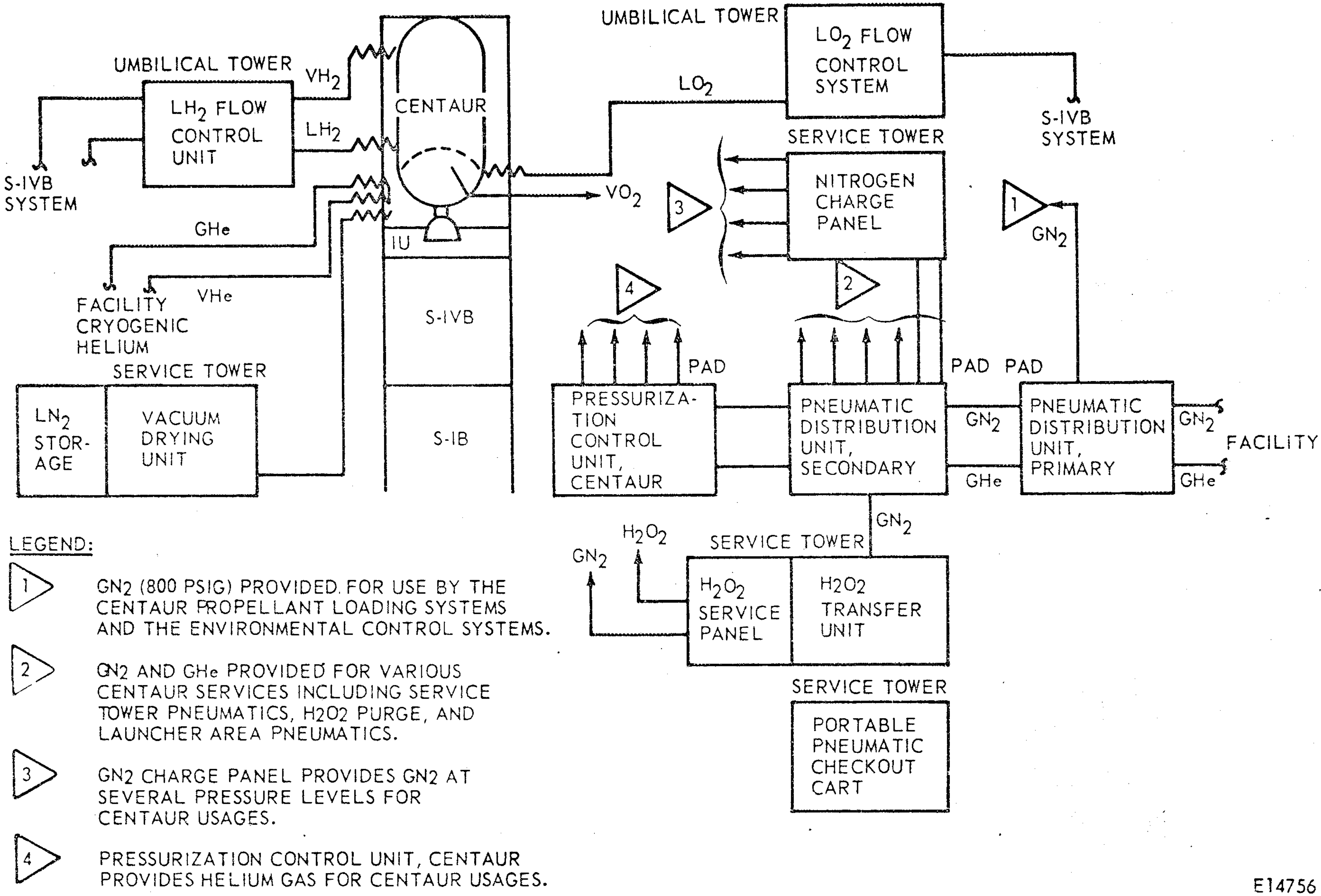

Figure VI-1. Centaur GSE Integration

countdown. It should be feasible to obtain the Centaur helium from the S-IVB heat exchanger rather than from a new unit if the peak Centaur load is programed out of phase with the S-IVB peak load.

C. CENTAUR HYDROGEN PEROXIDE SYSTEM SERVICING

The present Centaur hydrogen peroxide servicing unit satisfies all of the necessary hydrogen peroxide requirements and is recommended for use with the Saturn IB/Centaur vehicle. This system consists of a mobile cart (containing a storage tank) , valves, a transfer pump measuring equipment and a nitrogen purge system. The system is manually operated from the service structure platform prior to service structure removal. A vacuum drying sytem operates in conjunction with the service cart to remove small quantities of hydrogen peroxide from the vehicle after a test or an abort.

D. CENTAUR HYDRAULICS SYSTEM SERVICING

The Centaur hydraulic service cart is recommended to service the engine hydraulic systems. This unit consists of a hydraulic fluid reservoir, a pump, filters, and the necessary lines and connections to allow connection into the ground-pressure and ground-return disconnects of the Centaur onboard hydraulic system. This unit will service the stage from service platform number 5. Additional hydraulics will be required in the umbilical tower for the retraction of the new Centaur-peculiar upper and lower umbilical booms.

Centaur hydraulic system service requirements are summarized by function in table VI-2.

Table VI-2 Centaur Hydraulic System Requirements

FUNCTION	REQUIREMENT
Pressure	250 to 1200 psig
Flowrate	2 ± 0.5 gpm
Temperature	50 to 100 °F
Hydraulic Fluid	Per MIL-H-5606A
Contamination	Unknown

E. CENTAUR PNEUMATICS EQUIPMENT

The recommended Centaur GSE pneumatic equipment includes a pneumatic check-out cart, pressurization control unit, nitrogen charge panel, and primary and secondary pneumatic distribution units. These items are listed in table VI-1.

F. CENTAUR ENVIRONMENTAL CONDITIONING SYSTEM

Centaur environmental control system (ECS) requires heated or cooled air or nitrogen. Nitrogen is substituted for air flow during LH_2 tanking operations. Table VI-3 defines Centaur ECS requirements and Saturn IB system capabilities.

Unit 1 shown in table VI-3 is one of four units currently existing in the Saturn IB system. One of these units is always held in reserve. The flow capacity of each unit is approximately 300 pounds-per-minute of conditioned air or nitrogen.

Total air-conditioning requirements for Launch Complexes 34 and 37B will increase because of larger contained volumes and new environments resulting from the addition of the Centaur stage to the Saturn IB vehicle. One additional environmental conditioning unit will provide an adequate capability for supplying these additional needs.

Table VI-3. Saturn/Centaur Environmental Control System

	SATURN CAPABILITIES		CENTAUR REQUIREMENTS	
FUNCTION	S-IVB/IU Unit 1	SERVICE MODULE Unit 1	AFT COMPARTMENT	FORWARD COMPARTMENT
Supply Temperature	45 to 120 F	50 to 80 F	60 to 125 F	45 to 80 F
Flow	150 lb/min	100 lb/min	155 ± 15 lb/min	90 ± 20 lb/min

SECTION VII. COMPONENT TEST REQUIREMENTS SUMMARY

The development, qualification, and feasibility tests required of the propulsion systems, subsystems, and components of the S-IB, S-IVB, and Centaur stages are listed in table VII-1.

TABLE VII-1. Baseline Saturn IB/Centaur Launch Vehicle Test Requirements

STAGE	REQUIREMENT
S-IB	Existing Components - No Dev. and Qual. Tests [1] New Components - N/A
S-IVB	Existing Components - No Dev. and Qual. Tests New Components - Dev. and Qual. Tests of Retrorockets
CENTAUR	Existing Components - No Dev. and Qual. Tests New Components - Dev. and Qual. Tests of: 1) Fluid Umbilical Systems a) Lines, b) Structures, c) Disconnects, d) Disconnect Panels, e) Umbilicals, f) Lanyards 2) Pneumatic Control Systems Pneumatic Latching Mechanisms 3) Auxiliary Propulsion Systems a) Retrorockets, b) Shroud Separation System Feasibility (Functional) Tests [2] : 1) Helium Storage System 2) Propellant Tank Vent Systems 3) H_2O_2 Storage System 4) Auxiliary Propulsion System 3-lb Thrust Nozzles 5) LH_2 Tank Anti-Slosh Baffle System

Notes:

[1] - Dev. & Qual. -- Refers to new hardware items:

a) Rockets -- Normal Development and Qualification test program.

b) Umbilicals - Normal Development and Qualification Test program; plus dynamic separation test, flow tests, etc.

Notes (Continued):

c) Pneumatic Latching - Normal Development and Qualification test program; plus dynamic separation tests.

d) Shroud Separation - Complete dynamic separation test to include simulated vehicle accelerations and all anticipated degrees of freedom (cold gas system: lateral and vertical; solid rocket system: lateral). Since the stated axial acceleration at shroud separation is 0.8 G_o, the testing can be done on the ground under 1.0 G_o, and the results applied safely to the in-flight case.

2 - Feasibility - Refers to functional tests of existing developed hardware used in slightly different manner than originally intended but not requiring re-qualification.

Notes (Continued):

c) Pneumatic Latching - Normal Development and Qualification test program; plus dynamic separation tests.

d) Shroud Separation - Complete dynamic separation test to include simulated vehicle accelerations and all anticipated degrees of freedom (cold gas system: lateral and vertical; solid rocket system: lateral). Since the stated axial acceleration at shroud separation is 0.8 G_o, the testing can be done on the ground under 1.0 G_o, and the results applied safely to the in-flight case.

2 - Feasibility - Refers to functional tests of existing developed hardware used in slightly different manner than originally intended but not requiring re-qualification.

SECTION VIII. SATURN IB/CENTAUR

PRELIMINARY LAUNCH SEQUENCE - PROPULSION

Figure VIII-1 presents a compilation of propulsion event sequences for terminal launch operations. The Centaur events shown have been compressed into the final four hours to allow concentration of operations during this period and to assure that recycle operations will accomplish all critical service and checkout functions for this stage. In many cases the sequence of events is contingent upon other operations not shown, such as systems tests and telemetry checks, etc.

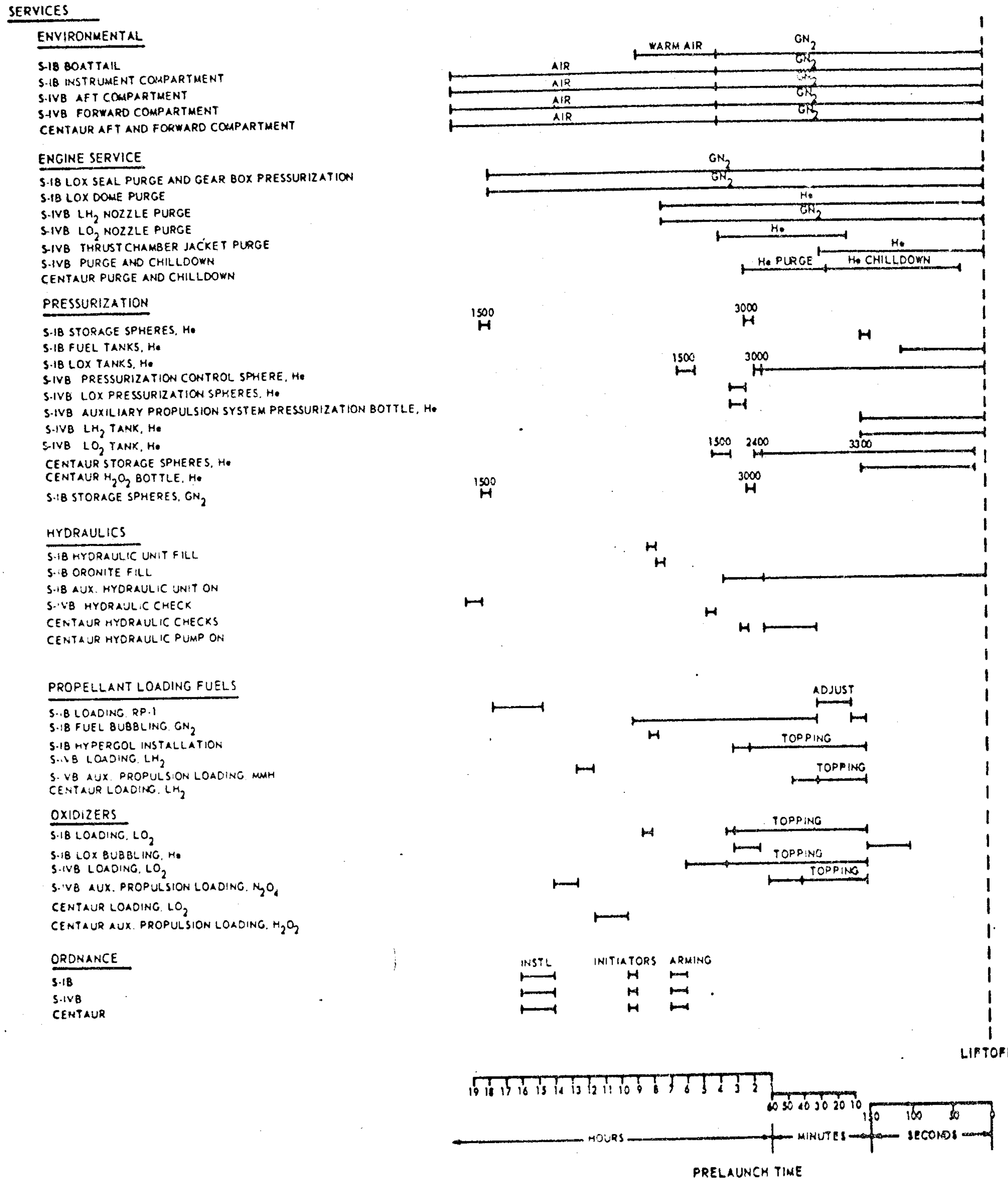

Figure VIII-1. Preliminary Launch Sequence - Propulsion

APPENDIX A - SATURN IB/CENTAUR
LAUNCH VEHICLE PERFORMANCE PROFILE

A Saturn IB/Centaur trajectory representing a 1969 fly-by mission with launch window of about 120 days was chosen as a reference trajectory. The flight weights profile for this trajectory is presented in table A-1. Table A-2 presents the significant trajectory parameters as functions of flight time for the reference trajectory. The Saturn IB/Centaur flight environment as defined by these parameters is typical of the environment encountered by all trajectories in this injection energy range. Maximum dynamic pressure and maximum axial acceleration peaks encountered will vary less than 1 per cent from the reference trajectory peak values.

TABLE A-1. FLIGHT STAGE SEQUENCING FOR FLIGHT PERFORMANCE ANALYSIS

VEHICLE:	Saturn IB/Centaur
FIRST STAGE:	8 x 200K Thrust (S. L.)
* SECOND STAGE:	1 x 200K Thrust (VAC.)
THIRD STAGE:	2 x 15K Thrust (VAC.)

EVENT		WEIGHT	
LIFT-OFF (Az. = 90°; Lat. = 28.52°) $\frac{T}{W} = 1.224$			1,302,985
Strap-on Propellant Consumed			
Jettison Strap-on Inert Weight			
Max. Q = 606.0 psf			
Max a_x = 4.057 g			
Inboard Shutdown - Propellants Consumed		862,876	
Jettison Inboard Thrust Decay Propellants		2,145	
Outboard Shutdown - Propellants Consumed		18,223	
FIRST STAGE BURNOUT			419,741
Stage Inert Weight		107,005	
S-IVB Aft Frame	25		
Stage Dry	85,497		
Residuals and Reserve	11,250		
Outboard Thrust Decay Propellant	2,099		
Frost and Service Items	1,586		
Interstage	6,548		
Separation and Start Losses		668	
SECOND STAGE IGNITION			312,068
Jettison Ullage Rocket Cases		225	
Jettison Third Stage Shroud		5,600	
Mainstage Propellants Consumed		230,359	
SECOND STAGE BURNOUT			75,884
Stage Inert Weight		29,527	
Stage Dry	24,338		
Residuals, Decay & Roll Propellant	1,772		
Reserves (PUR)	127		
I. U.	2,550		
Interstage	740		
Separation and Start Losses		136	
THIRD STAGE IGNITION			46,221
Mainstage Propellants Consumed (First Burn)		5,150	
THIRD STAGE CUT-OFF (Injection in 100 n. mi. Parking Orbit)			41,071
Weight Loss During Coast		255	
Propellant (Decay, Boiloff)	255		
Other Consumables			
Restart Losses			
Mainstage Propellants Consumed (Second Burn)		24,456	

THIRD STAGE BURNOUT (Injection: $C_3 = 1.75 \times 10^8$ ft^2/sec^2)			16,390
Stage Inert Weight		6,736	
Stage Dry	5,792		
Residuals	550		
Reserve (ΔV = 100 m/sec)	394		
I. U.			
PAYLOAD			9,654

* Utilizing Programmed Mixture Ratio Shift.

Table A-2
Saturn IB/Centaur Reference Trajectory

SATURN IB/CENTAUR - MARS FLY-BY REFERENCE TRAJECTORY - RUN NO.0669

TIME SEC	ALT FT	VELR FPS	THETAR DEG	WEIGHT LB	THRUST LB	DYNPR PSF	AXACC G
0.	0.	0.	0.	1302974.	1594521.	0.	1.22
5.00	94.	38.8	-0.03	1272602.	1595139.	1.7	1.25
10.00	393.	82.3	-0.05	1242230.	1597103.	7.7	1.28
15.00	922.	130.7	-0.08	1211857.	1600581.	19.1	1.32
20.00	1707.	184.7	0.44	1181485.	1605719.	37.4	1.35
25.00	2776.	244.5	1.46	1151113.	1612418.	63.5	1.39
30.00	4158.	310.4	2.60	1120741.	1620725.	98.4	1.43
35.00	5885.	383.2	4.13	1090369.	1630844.	142.4	1.47
40.00	7989.	463.5	6.03	1059996.	1642122.	195.8	1.51
45.00	10504.	552.0	8.28	1029624.	1655005.	257.0	1.56
50.00	13462.	650.1	10.80	999252.	1668918.	325.0	1.62
55.00	16897.	758.3	13.54	968880.	1683971.	395.1	1.67
60.00	20840.	876.8	16.44	938508.	1698550.	467.8	1.72
65.00	25308.	1003.0	19.42	908136.	1713251.	531.0	1.73
70.00	30291.	1133.0	22.47	877764.	1727423.	574.4	1.75
73.00	33522.	1216.0	24.31	859540.	1735400.	592.0	1.79
74.00	34640.	1244.9	24.93	853466.	1737923.	597.0	1.81
75.00	35780.	1274.6	25.55	847392.	1740494.	600.2	1.83
76.00	36940.	1305.2	26.16	841317.	1742898.	603.6	1.85
77.00	38122.	1336.5	26.78	835243.	1745268.	606.0	1.87
78.00	39326.	1368.7	27.39	829168.	1747682.	606.0	1.90
79.00	40552.	1401.9	28.00	823094.	1749787.	608.0	1.92
80.00	41801.	1435.9	28.61	817020.	1751918.	607.8	1.94
81.00	43073.	1470.8	29.21	810945.	1754087.	604.9	1.97
82.00	44368.	1506.8	29.82	804871.	1756272.	599.3	1.99
85.00	48398.	1620.7	31.60	786647.	1761842.	581.9	2.07
90.00	55620.	1831.7	34.46	756275.	1769654.	522.7	2.21
95.00	63513.	2069.4	37.18	725903.	1775354.	441.6	2.34
100.00	72117.	2332.8	39.72	695531.	1779546.	354.8	2.48
105.00	81465.	2622.7	42.09	665159.	1782401.	278.0	2.62
110.00	91587.	2939.8	44.29	634787.	1784258.	215.3	2.76
115.00	102517.	3285.4	46.31	604415.	1785472.	161.2	2.92
125.00	126942.	4068.7	49.88	543671.	1786731.	79.5	3.27
130.00	140518.	4510.7	51.45	513298.	1786981.	59.4	3.47
135.00	155069.	4990.0	52.88	482926.	1787188.	36.7	3.69
140.00	170654.	5510.7	54.18	452554.	1787284.	26.2	3.94
142.05	177362.	5737.4	54.68	440096.	1787317.	21.9	4.06

TIME=142.05 EVENT - S-IB INBOARD CUT-OFF

TIME SEC	ALT FT	VELR FPS	THETAR DEG	WEIGHT LB	THRUST LB	DYNPR PSF	AXACC G
142.50	178854.	5764.0	54.71	436587.	891819.	21.4	2.04
145.00	187202.	5883.1	55.29	428994.	891830.	17.9	2.08
148.05	197465.	6034.5	55.95	419727.	891844.	12.6	2.12

TIME=148.05 EVENT - S-IB OUTBOARD BURNOUT

TIME SEC	ALT FT	VELR FPS	THETAR DEG	WEIGHT LB	THRUST LB	DYNPR PSF	AXACC G
148.50	198981.	6032.3	55.97	312722.	0.	11.6	-0.
153.55	215644.	5943.0	57.14	312722.	0.	8.9	-0.

Table A-2 (Continued)
Saturn IB/Centaur Reference Trajectory

TIME=153.55 EVENT -S-IVB FULL THRUST

TIME SEC	ALT FT	VELI FPS	THETAI DEG	WEIGHT LB	THRUST LB	DYNPR PSF	AXACC G
154.00	217090.	7119.8	63.17	311838.	205000.	8.8	0.66
163.00	245315.	7183.3	64.79	307507.	205000.	4.5	0.67
168.00	260415.	7234.0	65.66	304627.	230000.	1.3	0.76
173.00	275133.	7289.2	66.50	301909.	230000.	0.6	0.76
178.00	289474.	7347.5	67.34	299191.	230000.	0.5	0.77
183.00	303441.	7408.8	68.16	296473.	230000.	0.3	0.78
188.00	317037.	7473.1	68.96	293754.	230000.	0.1	0.78
193.00	330265.	7540.4	69.75	291036.	230000.	0.	0.79
198.00	343129.	7610.6	70.53	288318.	230000.	0.	0.80
203.00	355633.	7683.8	71.29	285600.	230000.	0.	0.81
208.00	367780.	7759.8	72.03	282882.	230000.	0.	0.81
213.00	379576.	7840.3	72.75	274564.	230000.	0.	0.84
218.00	391028.	7924.8	73.45	271846.	230000.	0.	0.85
223.00	402142.	8012.1	74.14	269128.	230000.	0.	0.85
228.00	412923.	8102.3	74.81	266410.	230000.	0.	0.86
233.00	423373.	8195.3	75.46	263692.	230000.	0.	0.87
238.00	433496.	8291.1	76.09	260974.	230000.	0.	0.88
243.00	443299.	8389.8	76.71	258256.	230000.	0.	0.89
248.00	452783.	8491.2	77.31	255538.	230000.	0.	0.90
253.00	461955.	8595.4	77.89	252820.	230000.	0.	0.91
258.00	470817.	8702.4	78.45	250102.	230000.	0.	0.92
263.00	479375.	8812.1	79.00	247384.	230000.	0.	0.93
268.00	487633.	8924.5	79.53	244666.	230000.	0.	0.94
273.00	495595.	9039.7	80.04	241948.	230000.	0.	0.95
278.00	503267.	9157.7	80.54	239230.	230000.	0.	0.96
283.00	510653.	9278.3	81.01	236512.	230000.	0.	0.97
288.00	517759.	9401.7	81.48	233794.	230000.	0.	0.98
293.00	524588.	9527.9	81.92	231075.	230000.	0.	1.00
298.00	531148.	9656.7	82.35	228357.	230000.	0.	1.01
303.00	537442.	9788.3	82.76	225639.	230000.	0.	1.02
308.00	543477.	9922.7	83.16	222921.	230000.	0.	1.03
313.00	549256.	10060.1	83.55	220203.	230000.	0.	1.04
318.00	554783.	10200.4	83.92	217485.	230000.	0.	1.06
323.00	560062.	10343.7	84.28	214767.	230000.	0.	1.07
328.00	565096.	10489.9	84.62	212049.	230000.	0.	1.08
333.00	569890.	10639.3	84.96	209331.	230000.	0.	1.10
338.00	574449.	10791.6	85.28	206613.	230000.	0.	1.11
343.00	578776.	10947.1	85.58	203895.	230000.	0.	1.13
348.00	582875.	11105.7	85.88	201177.	230000.	0.	1.14
353.00	586752.	11267.6	86.16	198459.	230000.	0.	1.16
358.00	590411.	11432.6	86.44	195741.	230000.	0.	1.18
363.00	593857.	11600.9	86.70	193023.	230000.	0.	1.19
368.00	597095.	11772.6	86.95	190305.	230000.	0.	1.21
373.00	600130.	11947.6	87.18	187587.	230000.	0.	1.23
378.00	602968.	12126.1	87.41	184869.	230000.	0.	1.24
383.00	605613.	12308.0	87.62	182151.	230000.	0.	1.26
388.00	608073.	12493.6	87.83	179433.	230000.	0.	1.28
393.00	610352.	12682.8	88.02	176715.	230000.	0.	1.30

Table A-2 (Continued)
Saturn IB/Centaur Reference Trajectory

TIME SEC	ALT FT	VELI FPS	THETAI DEG	WEIGHT LB	THRUST LB	DYNPR PSF	AXACC G
398.00	612456.	12875.7	88.20	173997.	230000.	0.	1.32
403.00	614393.	13072.4	88.37	171278.	230000.	0.	1.34
408.00	616169.	13273.0	88.53	168560.	230000.	0.	1.36
413.00	617789.	13477.6	88.68	165842.	230000.	0.	1.39
418.00	619263.	13686.3	88.82	163124.	230000.	0.	1.41
423.00	620596.	13899.2	88.96	160406.	230000.	0.	1.43
428.00	621797.	14116.4	89.08	157688.	230000.	0.	1.46
433.00	622873.	14337.9	89.19	154970.	230000.	0.	1.48
438.00	623833.	14564.0	89.29	152252.	230000.	0.	1.51
443.00	624686.	14794.8	89.38	149534.	230000.	0.	1.54
448.00	625440.	15030.4	89.46	146816.	230000.	0.	1.57
453.00	626097.	15249.8	89.56	144296.	190000.	0.	1.32
458.00	626612.	15452.0	89.67	142074.	190000.	0.	1.34
463.00	626981.	15658.0	89.78	139851.	190000.	0.	1.36
468.00	627211.	15868.0	89.88	137629.	190000.	0.	1.38
473.00	627306.	16082.0	89.98	135407.	190000.	0.	1.40
478.00	627272.	16300.1	90.07	133184.	190000.	0.	1.43
483.00	627118.	16522.4	90.15	130962.	190000.	0.	1.45
488.00	626850.	16749.1	90.22	128740.	190000.	0.	1.48
493.00	626474.	16980.3	90.29	126517.	190000.	0.	1.50
498.00	625997.	17216.1	90.35	124295.	190000.	0.	1.53
503.00	625429.	17456.6	90.40	122072.	190000.	0.	1.56
508.00	624775.	17702.0	90.45	119850.	190000.	0.	1.59
513.00	624045.	17952.5	90.49	117628.	190000.	0.	1.62
518.00	623248.	18208.2	90.52	115405.	190000.	0.	1.65
523.00	622392.	18469.3	90.55	113183.	190000.	0.	1.68
528.00	621486.	18736.0	90.57	110961.	190000.	0.	1.71
533.00	620541.	19008.4	90.58	108738.	190000.	0.	1.75
538.00	619567.	19286.9	90.58	106516.	190000.	0.	1.78
543.00	618574.	19571.6	90.58	104293.	190000.	0.	1.82
548.00	617573.	19862.7	90.58	102071.	190000.	0.	1.86
553.00	616576.	20160.6	90.56	99849.	190000.	0.	1.90
558.00	615595.	20465.5	90.54	97626.	190000.	0.	1.95
563.00	614643.	20777.7	90.51	95404.	190000.	0.	1.99
568.00	613733.	21097.6	90.48	93181.	190000.	0.	2.04
573.00	612878.	21425.4	90.44	90959.	190000.	0.	2.09
578.00	612095.	21761.5	90.39	88737.	190000.	0.	2.14
583.00	611397.	22106.4	90.34	86514.	190000.	0.	2.20
588.00	610801.	22460.5	90.27	84292.	190000.	0.	2.25
593.00	610324.	22824.2	90.21	82070.	190000.	0.	2.32
598.00	609984.	23198.1	90.13	79847.	190000.	0.	2.38
603.00	609799.	23582.7	90.05	77625.	190000.	0.	2.45
606.92	609775.	23891.8	89.98	75884.	190000.	0.	2.50

TIME=606.92 EVENT - S-IVB BURNOUT

607.00	609776.	23891.8	89.98	46357.	0.	0.	-0.
615.42	609710.	23891.9	90.06	46357.	0.	0.	-0.

Table A-2 (Continued)
Saturn IB/Centaur Reference Trajectory

TIME=615.42 EVENT -CENTAUR IGNITION

TIME SEC	ALT FT	VELI FPS	THETAI DEG	WEIGHT LB	THRUST LB	DYNPR PSF	AXACC G
615.50	609708.	23893.6	90.06	46216.	30000.	0.	0.65
620.00	609592.	23987.0	90.06	45911.	30000.	0.	0.65
625.00	609451.	24091.7	90.07	45574.	30000.	0.	0.66
630.00	609298.	24197.2	90.07	45236.	30000.	0.	0.66
635.00	609138.	24303.6	90.08	44898.	30000.	0.	0.67
640.00	608972.	24410.9	90.08	44560.	30000.	0.	0.67
645.00	608805.	24519.1	90.08	44222.	30000.	0.	0.68
650.00	608640.	24628.2	90.08	43884.	30000.	0.	0.68
655.00	608480.	24738.2	90.07	43547.	30000.	0.	0.69
660.00	608328.	24849.1	90.07	43209.	30000.	0.	0.69
665.00	608189.	24960.9	90.06	42871.	30000.	0.	0.70
670.00	608065.	25073.7	90.05	42533.	30000.	0.	0.71
675.00	607959.	25187.4	90.04	42195.	30000.	0.	0.71
680.00	607876.	25302.0	90.03	41857.	30000.	0.	0.72
685.00	607819.	25417.6	90.02	41520.	30000.	0.	0.72
690.00	607793.	25534.2	90.00	41182.	30000.	0.	0.73
691.64	607791.	25572.5	90.00	41071.	30000.	0.	0.73

TIME=691.64 EVENT -CENTAUR FIRST BURN CUTOFF-PARKING ORBIT INJECTION

TIME SEC	ALT FT	VELI FPS	THETAI DEG	WEIGHT LB	THRUST LB	DYNPR PSF	AXACC G
700.00	607799.	25771.6	89.99	40281.	30000.	0.	0.74
725.00	608160.	26383.4	89.93	38592.	30000.	0.	0.78
750.00	609770.	27021.1	89.78	36903.	30000.	0.	0.81
775.00	613664.	27686.2	89.55	35213.	30000.	0.	0.85
800.00	620972.	28380.3	89.24	33524.	30000.	0.	0.89
825.00	632932.	29105.9	88.84	31835.	30000.	0.	0.94
850.00	650901.	29865.5	88.35	30146.	30000.	0.	1.00
875.00	676369.	30662.6	87.78	28457.	30000.	0.	1.05
900.00	710979.	31501.6	87.11	26767.	30000.	0.	1.12
925.00	756538.	32387.6	86.34	25078.	30000.	0.	1.20
950.00	815048.	33327.5	85.48	23389.	30000.	0.	1.28
975.00	888729.	34329.8	84.51	21700.	30000.	0.	1.38
1000.00	980063.	35405.6	83.44	20010.	30000.	0.	1.50
1025.00	1091834.	36568.9	82.27	18321.	30000.	0.	1.64
1050.00	1227199.	37838.7	80.98	16632.	30000.	0.	1.80
1059.42	1285025.	38349.5	80.46	15996.	30000.	0.	1.88

TIME=1059.42 EVENT - CENTAUR BURNOUT

INJECTION CONDITIONS PAYLOAD - 9654 POUNDS
ENERGY PARAMETER - 1.75E08 SQFT/SQSEC

APPENDIX B - BIBLIOGRAPHY

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4) North American/Rocketdyne Report R-3825-1, "J-2 Engine Data Manual," (Unclassified), 18 June 1964, Confidential.

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